Bangor University

DOCTOR OF PHILOSOPHY

Targeting perception of effort to modify the limits to human endurance

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Award date:
2014

Awarding institution:
Bangor University

TARGETING PERCEPTION OF EFFORT TO MODIFY THE LIMITS TO HUMAN ENDURANCE

By

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Thesis submitted to Bangor University

In fulfilment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

PRIFYSGOL
BANGOR
UNIVERSITY

1884

2014

Summary

The factors that limit human endurance have received extensive scientific scrutiny. Traditionally these limiting factors have been attributed to physiological processes occurring within the muscles, the cardiovascular system, or spinal and supraspinal sites. Consequently, interventions designed to provoke alterations in endurance performance are generally tailored towards targeting these physiological processes.

Recent research suggests that endurance performance is also limited by psychobiological influences: specifically perception of effort (RPE). On this basis the psychobiological model of endurance performance predicts that any physiological or psychological factor affecting RPE will alter endurance performance. As such, this thesis sought to elicit alterations in RPE, and consequently physical endurance, using psychobiological strategies that were implemented to directly target RPE.

In Chapter 2 it was established that a two week motivational self-talk intervention significantly reduced RPE at 50% iso-time while enhancing cycling time to exhaustion (TTE) by 18%. This equated to a *very likely* beneficial practical effect on TTE (beneficial/trivial/harmful%; 99/1/0%).

In Chapter 3, a six week cognitive training protocol was designed to repeatedly target the anterior cingulate cortex due to its neuro-cognitive connections with cognitive and physical effort. This approach did not significantly alter RPE or TTE at exercise intensities of 80% or 65% peak power output (PPO). A *likely* beneficial practical effect on TTE was nonetheless evident at 65% PPO (83/15/2%).

Using subliminal affective priming in Chapter 4, RPE was significantly lower and TTE significantly greater when participants were subliminally primed with happy faces while cycling compared to an alternative visit when they were subliminally primed with sad faces. This difference in TTE was of *possible* practical value (70/30/0%). Following on from this,

Chapter 5 implemented a single subject approach using a randomization tests design and illustrated that subliminally primed action words significantly reduced RPE and enhanced TTE compared to subliminally primed inaction words.

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List of Abbreviations

ACC	Anterior cingulate cortex
ANOVA	Analysis of variance
BET	Brain endurance training
BRUMS	Brunel mood scale
CNS	Central nervous system
CV	Coefficient of variation
EMG	Electromyography
HRV	Heart rate variability
Km	Kilometres
PPO	Peak power output
RPE	Rating of perceived effort (or exertion)
RPM	Revolutions per minute
s	Seconds
SPSS	Statistical package for social sciences
TTE	Time to exhaustion
μV	Microvolts
$\dot{V}O_{2max}$	Maximum oxygen uptake
W	Watts

Acknowledgements

Firstly I would like to thank the School of Sport, Health, and Exercise Sciences for affording me the opportunity to conduct my PhD research; and for providing me with such fantastic support and so many opportunities for academic development. It has been a pleasure to be based in this wonderfully unique and vibrant academic department. Along with this I would like to express appreciation to my original PhD supervisor, Professor Samuele Marcora. Sam, thanks for taking someone with a stubbornly physiological mind-set and changing my whole perspective on sport and exercise performance forever. I am not sure if I have ever met an academic with such an insightful, and yet pragmatic, way of thinking.

Similarly, I would like to express sincere gratitude to my thesis chair, Professor Neil Walsh; and to Dr James Hardy and Dr Amy Hayes who assumed responsibility for my thesis supervision after Samuele's departure to another institution during my PhD. I would not have been able to continue my studies without this. James in particular, the influence that you have had on my development as an academic is difficult to put into words, and it is something that I will never forget. If there is another researcher in the UK who is as generous with their time, wisdom, and trust I would seriously like to meet them. I'll miss the impromptu late afternoon brain storming sessions! Also, few PhD submissions should pass through SSHES without an indebted mention to the glue that holds together much of our research; technicians (and running partners) Kevin Williams, Jason Edwards, and Shaun Mckiernan. Your ceaseless work and assistance is something that I'm sure no one takes for granted.

Helma de Morree and Walter Staiano, thank you for all of the help and advice early on. To all of the friends with whom I shared an office; Justin Lawley, Val Dennehy, Julian Owen, and Niamh Reilly, it was a lot of fun. Justin, in a parallel universe I'm about to submit a PhD on Star Wars, UFO's, and all things outer space! Likewise, thank you to all of the participants who made my work possible. It has been a joy to meet some incredible characters (and athletes). I am glad to say that I am still in touch with many of you.

I should also mention my friends back home who I'm sure have been somewhat bemused by my reclusiveness in the last few years. I have not seen you as much as I should have. Finally, thank you to my mum, dad, and extended family who have always encouraged me to follow happiness and fulfilment above all else. Like many others in sports science, I am very fortunate to be involved in a profession that is more of a hobby than a job. That is because of your support and encouragement during all of the big decisions that I have made.

CHAPTER 1

General Introduction

1.1. Human Endurance, Fatigue and Exhaustion

Fossil records suggest that the capacity for long distance endurance in bipedal hominids evolved approximately two million years ago (Lieberman & Bramble, 2007). It was only during the seventeenth century however when men began to feature in wager based foot races that humans frequently started to utilize their proclivity for endurance in a competitive manner (Radford & Ward-Smith, 2003). Since this time, the popularity of competitive endurance sports has proliferated globally amongst both recreational and elite athletes, and encompassing events ranging in distance from the 4 km individual cycling pursuit to the 42 km marathon, and the 4,486 km transcontinental ultra-marathon. As a result, the factors that limit human endurance are now a topic of extensive scientific investigation and debate (Amann & Secher, 2009; Hargreaves, 2008; Marcora, 2009; Noakes & Tucker, 2008).

The limit to human endurance during physical tasks is signified by either a reduction in exercise intensity, or by complete task cessation. Respectively, these two occurrences are characterized by the concepts of physical fatigue and exhaustion. Operationally, physical fatigue has been defined as any exercise-induced reduction in the ability to exert muscle force or power regardless of whether or not the task can be maintained (Gandevia, 2001). Exhaustion on the other hand is said to represent an inability to continue with a prescribed task (Marino, Gard, & Drinkwater, 2011). Though physical fatigue and exhaustion are conceptually different, some investigators have concluded that exhaustion results from the progressive development of physical fatigue (Allen, Lamb, & Westerblad, 2008; Amann & Dempsey, 2008; MacIntosh & Shahi, 2011a), hence exhaustion is largely regarded as a physiological phenomenon (see Figure 1.1). Accordingly, since the work of physiologists such as Lombard (1892), Hill and Lupton (1923), and Merton (1954) beginning over a century ago, the proposal that physical endurance is limited by physiological processes has been a prominent feature of sport and exercise science.

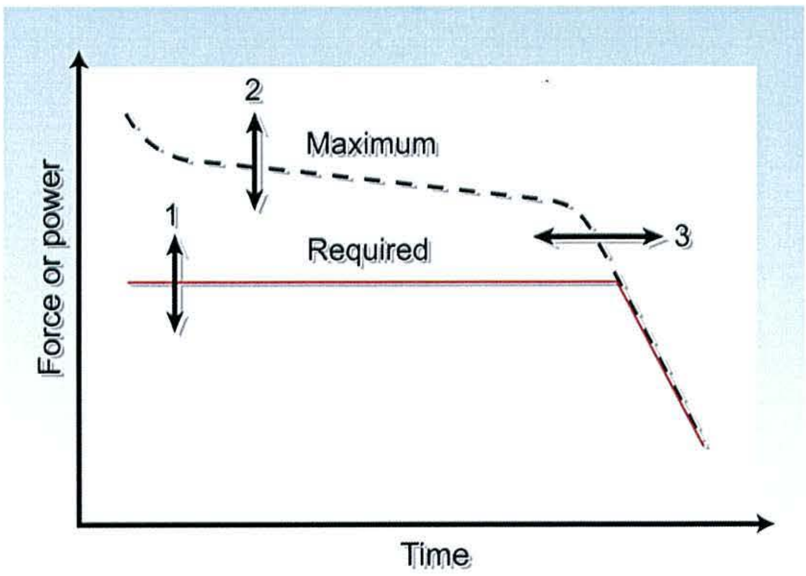

Figure 1.1. A schematic (Allen et al., 2008) to illustrate the proposed factors that determine when physiological exhaustion occurs. Dashed line shows how the maximum force (or power) declines during repeated tetani. Solid red line indicates a submaximal force required for a particular activity. Exhaustion (failure to produce the required force) occurs at the intersection of the two lines. Increases and decreases in the required force (arrow 1) will cause earlier and later onset of exhaustion, respectively. Increases and decreases in the maximum force that the muscle can produce (arrow 2) will also change the time to exhaustion. Finally, changes in the intrinsic fatigability of the muscle (arrow 3) will also change the time to exhaustion.

1.2. Physiological Models of Fatigue

Since the early research into physiological fatigue, numerous scientific models have been developed to identify its underlying causes. Conventionally, many of these models propose that physical endurance is limited by processes occurring either within the muscle itself due to musculo-energetic or biochemical factors (Allen et al., 2008; Fitts, 2008), or by processes occurring within the cardiorespiratory system (Bassett & Howley, 2000). More recently, muscle fatigue has also been attributed to processes occurring at supraspinal sites

(Taylor & Gandevia, 2008), while contemporary investigators have further sought to combine these processes into one integrated physiological model of fatigue (Amann & Dempsey, 2008; Noakes, 1997)

Fatiguing processes within the active muscles or the cardiorespiratory system have been investigated and endorsed by researchers for many decades (Coyle et al., 1983 Fitts, Courtright, Kim, & Witzmann, 1982; Merton, 1954; Westerblad, Lee, Lännergren, & Allen, 1991). Although some of these models of differ on their basic hypotheses, the suggestion that endurance is limited by physiological processes is a key contention of each. In particular, models involving the cardio-respiratory, metabolic and musculo-energetic systems have received considerable investigation. This includes the role of restricted oxygen delivery to the working muscles (González-Alonso & Calbet, 2003) due to a reduction in cardiac output and muscle blood flow (Amann & Calbet, 2008); the influence of respiratory muscle fatigue (Romer & Polkey, 2008); the intra-muscular accumulation of metabolic by-products such as lactate, hydrogen ions and adenosine diphosphate which are proposed to impair excitation contraction coupling (Fitts, 2007); attenuated cross bridge binding due the build-up of inorganic phosphate within the sarcoplasmic reticulum (Allen et al., 2008); and the depletion of energetic resources such as muscle and liver glycogen (Hargreaves et al., 1997).

Although many cardio-respiratory, biochemical and musculo-energetic models of muscle fatigue are still widely advocated and investigated, recent models of supraspinal fatigue have developed alongside these to investigate factors such as neurotransmitter fluctuations (Foley & Fleshner, 2008) and descending drive from motor areas within the brain (Gandevia, 2001). In addition, some investigators argue that these models are integrated such that supraspinal fatigue is regulated by cardiorespiratory and biochemical processes. For instance, feedback from group III and IV muscle afferents has been proposed to affect the central nervous system (CNS) by inhibiting or decreasing the firing frequency of the motor neurons (Bigland-Ritchie, Dawson, Johansson, & Lippold, 1986; Martin, Weerakkody, Gandevia, & Taylor, 2008). As these Group III and IV afferents are partly stimulated by the accumulation of muscle metabolites, this has been suggested to restrict central motor drive to the working muscles during endurance exercise in order to limit peripheral fatigue (see Figure 1.2), the result of which is a constraint on physical endurance (Amann et al., 2008). Similarly, despite recent adjustments to account for psychological considerations (Noakes, 2012), the central governor model (Noakes, 1997) proposes that endurance is limited by the neural control of central motor output. In this model, central motor output depends on afferent feedback from a number of physiological processes, along with teleoanticipatory and psychological feedforward information (Tucker & Noakes, 2009), that converge in the brain. This is proposed to protect the organism from catastrophic perturbations in muscular and cardiovascular homeostasis. Accordingly, if homeostasis is threatened, central drive from the CNS to the active muscles is diminished and exercise cannot continue at the desired intensity.

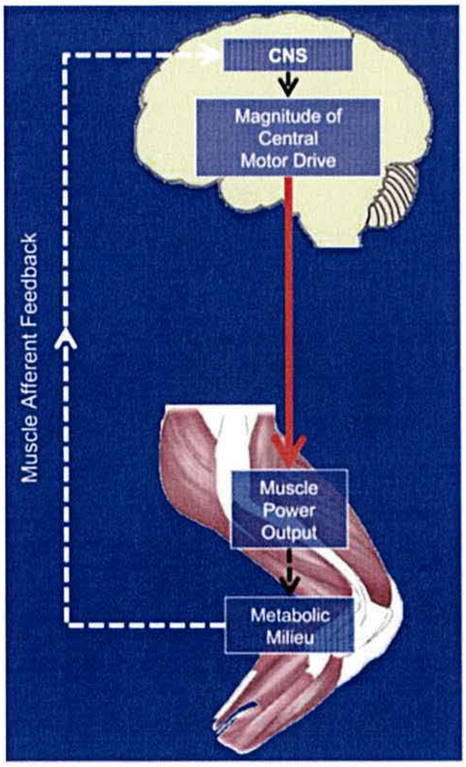

Figure 1.2. The afferent feedback model.

1.3. Physiological Interventions and Endurance Performance

The processes that limit physical endurance are a fundamental element of performance enhancement. This is because in most cases it is these limiting processes that must be targeted in order to elicit performance enhancement. As such, once a limiting process is identified, specific strategies can be implemented in order to directly target or overcome this limitation and instigate acute or long-term performance gains. Due to the prevailing concept that endurance performance is limited by physiological factors, the targeting of cardiorespiratory, biochemical, or musculo-energetic processes presently forms the basis of many performance enhancing strategies (Joyner & Coyle, 2008).

Historically, cardiorespiratory, biochemical, and musculo-energetic processes have been targeted for performance enhancement through physical training and nutritional interventions. For example, long-term performance enhancement has been achieved through physical training programmes that involve distance training and / or high intensity interval training to target cardio-respiratory parameters such as maximum oxygen uptake and oxygen kinetics (Tabata et al., 1996), as well as metabolic parameters such as the lactate threshold and critical power (Berger, Tolfrey, Williams, & Jones, 2006). Furthermore, ancillary strategies such as inspiratory muscle training (Bailey et al., 2010), variants of altitude training (Stray-Gundersen, Chapman, & Levine, 2001) and the prohibited use of erythropoietin (Spivak, 2001) have been used to influence endurance performance by increasing breathing capacity, red blood cell volume, and concomitantly, oxygen delivery to the working muscles.

In conjunction with physical training, nutritional strategies that focus on the timing, quantity and proportion of macronutrient intake are commonly implemented to facilitate endurance performance (Burke, Hawley, Wong, & Jeukendrup, 2011; Tipton & Wolfe, 2004). Additionally, the use of nitrogenous supplements (Bailey et al., 2009) as well as hydrogen buffers such as sodium bicarbonate and β alanine (Bellinger, Howe, Shing, & Fell, 2012) have been used to target cardio-respiratory and biochemical processes respectively. Furthermore, carbohydrate based strategies such as muscle glycogen loading (Rauch et al., 1995) and the consumption of carbohydrate based liquids (Jentjens, Achten, & Jeukendrup, 2004) have been endorsed to endurance athletes to overcome the limitation that is associated with muscle glycogen depletion. Finally, despite equivocal findings, the consumption of branched chain amino acids (Meeusen, Watson, & Dorvak, 2006) or the amino acid tyrosine (Tumilty, Davison, Beckmann, & Thatcher, 2011) have recently been explored as dietary approaches to mitigate supraspinal fatigue.

1.4. Psychobiological Perspectives and Endurance Performance

It is clear from the aforementioned research that physiological methods of endurance performance enhancement are effective. However, to achieve optimal athletic development it is imperative that all potential approaches to endurance performance enhancement are explored. In this regard, the opinion that physical endurance is restricted by physiological processes has meant that until recently, non-physiological investigations of the limits to physical endurance, and endurance performance enhancement, have been comparatively marginalised. This is an important consideration because despite the volume and diversity of models that advocate the limiting actions of physiological processes (e.g., Allen et al., 2008; Amman & Calbet, 2008; Fitts, 2007) none of these models are yet able to attribute a sufficient marker of direct causality; particularly when considering the common in vitro methodological use of isolated muscle fibres, and unnatural physiological temperatures (Allen et al., 2008). In some ways this latter consideration is reflected by the fact that while proponents of physiological fatigue still regard it as the limiting element of endurance (Amann et al., 2013; Levine, 2008; MacIntosh & Shahi, 2011a) some now also acknowledge the role of other potentially limiting factors involving psychobiology (Amann et al., 2013;

Hargreaves, 2008). Indeed it has been proposed that the limits to endurance performance are in fact regulated by psychobiological factors (Marcora, 2009). This emphasizes a conceptual shift towards a paradigm where endurance performance is influenced by conscious and voluntary factors such as effort and motivation (Marcora, 2008) as opposed to involuntary physiological processes (MacIntosh & Shahi, 2011a). Consequently, such a shift promotes a framework within which the psychobiological associations with physical endurance may be investigated more extensively.

Support for a paradigm that acknowledges conscious and voluntary psychobiological factors as a pivotal determinant of physical endurance can be obtained from three sources of investigation. Firstly, individuals voluntarily terminate exercise during prolonged and exhaustive exercise tasks while many of the cardiorespiratory and biochemical processes that are associated with physiological muscle fatigue remain in a physiological steady state at submaximal values (Baron et al., 2008). This has also been reported over a range of exercise intensities (Pires et al., 2011). Secondly, when cycling exercise is curtailed under the semblance of what would traditionally be regarded as exhaustion caused by physiological muscle fatigue; individuals are almost immediately able to regenerate a power output corresponding to three times that of the originally curtailed cycling task (Marcora & Staiano, 2010). Finally, there is an ever progressing collection of research demonstrating the influence of psychobiological factors upon physical endurance when manipulated independently of cardiorespiratory, metabolic and supraspinal processes. This includes psychological factors such as self-efficacy (Rudolph & McAuley, 1996), competition (Wilmore, 1968), music (Waterhouse, Hudson, & Edwards, 2010), placebo effect (Beedie, Stuart, Coleman, & Foad, 2006), deception (Stone et al, 2012) and verbal encouragement (Andreacci et al, 2002), and extends to psychobiological causes such as mental fatigue (Marcora, Staiano, & Manning, 2009), sleep deprivation (Martin, 1981), and hypnosis (Williamson et al., 2001).

1.5. Psychobiological Interventions and Endurance Performance

As already alluded to, findings from a number of psychobiological studies may to some degree challenge the contention that physiological fatigue exclusively determines physical endurance. For example, one of the earliest studies to illustrate the importance of psychobiological factors during endurance performance found that the addition of a competitor significantly elevated riding time and work output. Importantly, this occurred without any significant alterations in measured physiological variables (Wilmore, 1968). Furthermore, Beedie et al. (2006) demonstrated the impact of placebo treatments on endurance performance by reporting that an inert substance could mimic the dose response effect of caffeine such that mean power output during a 10 km cycling time trial decreased below baseline values by 1.4% when participants believed themselves to have ingested placebo, but improved by 1.3% and 3.1% respectively when they believed themselves to have consumed 4.5 $mg{\cdot}kg^{-1}$ and 9 $mg{\cdot}kg^{-1}$ of caffeine. In addition, Stone et al. (2012) have highlighted the effect of deception during endurance exercise with participants completing a 4000m cycling time trial faster when they competed against a previous personal performance that had been surreptitiously enhanced. Similarly, Morton (2009) reported that cycling time to exhaustion was extended by 18% in males when a visible clock was programmed to run 10% slower. Finally, Andreacci et al. (2002) were able to show that frequent verbal encouragement led to significantly greater effort on a maximal treadmill test when compared to infrequent or no encouragement.

Along with the findings from psychological studies of physical endurance, the implementation of psychobiological interventions has produced similar results. For example, Marcora et al. (2009) demonstrated that ninety minutes of prior mentally fatiguing activity significantly reduced cycling capacity at a constant intensity of 80% peak power output (PPO). This was despite no differences in physiological measures such as heart rate or end exercise lactate. Likewise, an equivalent period of mental fatigue impaired self-selected power output when individuals were instructed to cycle at constant levels of effort equating to 11 and 15 on the Borg 6-20 scale (Brownsberger, Edwards, Crowther, & Cottrell, 2013). In addition, Martin (1981) reported that 36 hours of sleep deprivation shortened treadmill walking time to exhaustion by 11%. Once more, this occurred without any difference in measured cardiorespiratory parameters, thus prompting the conclusion that a decreased exercise tolerance was caused by the psychological effects of sleep loss (Martin, 1981). Supportively, Oliver, Costa, Laing, Bilzon, and Walsh (2009) found that running distance covered over a set amount of time was compromised following one night of sleep deprivation, again in the absence of any measured physiological changes. Following on from this, Waterhouse, Hudson, and Edwards (2010) demonstrated that an undetectable 10% elevation in music tempo caused a 2.1% increase in distance cycled per unit time along with a 3.5% increase in power output when compared to the same track played at a regular tempo. Furthermore, slowing the track tempo by 10% resulted in a 3.8% reduction in distance covered and a 9.8% reduction in power output. While it should however be noted that this latter finding of Waterhouse et al. (2010) could also be associated with alterations in cadence according to music tempo Nakamura et al. (2010) have also found an increase in distance covered at an intensity equivalent to critical power when participants cycled to music that they rated as preferred versus non-preferred.

1.6. Perception of Effort

Sensation has been defined as the process of detecting a stimulus in the environment (Levine & Shefner, 1981). Perception on the other hand relates to the way in which one interprets the information gathered and processed by the senses resulting from this stimulus (Levine & Shefner, 1981). Perception is therefore a highly subjective interpretation of a particular stimuli (Weiten, 2007). It is suggested that perception results from a framework of neural dynamics that are constructed from the recent and remote results of action and its sensory consequences (Freeman, 2011). This includes, objects in the world, emotional valence and subjective behaviour (Morsella & Bargh, 2010). Perception is proposed to be integral to the sense of agency that accompanies the subjective sense of effort during physical tasks in healthy individuals (Lefarge & Franck, 2008). It is therefore an important feature of the willed and voluntary action that is thought to motivate goal-directed human behaviour (Demanet, Muhle-Karbe, Lynn, Blotenberg, & Brass, 2013).

Generally, individuals partaking in endurance exercise perceive an accompanying level of exertion that arises from the exercise task. This perception of exertion is intensity dependent (Ceci & Hasseman, 1991) and has traditionally been measured through subjective ratings obtained via Borg's rating of perceived exertion scale, and more recently the category-ratio (CR10) scale (Borg, 1982). The former scale is a linear scale that is designed to correspond to heart rate such that heart rate divided by ten equates to the subjective RPE. The latter scale is a positively accelerating scale based on curvilinear properties that are designed to elicit inter-individual comparisons (Noble & Robertson, 1996). In addition, the latter scale contains a dot at maximal to denote that it is open ended. This is to permit ratings above maximum and to avoid a proposed ceiling effect that may occur from participants failing to utilize the values at the top of the scale (Noble & Robertson, 1996). Both scales are reported to provide a valid and reliable marker of subjective effort (Borg, 1998) and a transformation table permits comparison between the two (Borg, 1998).

Originally, ratings of perceived exertion were proposed to result from a gestalt psychophysiological appraisal of many physiological afferent inputs and psychological processes (Noble & Robertson, 1996). More recently, authors have illustrated that these psychophysiological properties can be dissociated with a psychologically derived perception of effort occurring independently of the physiological perception of exertion or discomfort that occurs during a physical task (Swart, Lindsay, Lambert, Brown, & Noakes, 2012: Christian, Bishop, Billaut, & Girard, 2014). Furthermore, it has been proposed that this psychological perception of effort is in fact the major determinant of human endurance (Marcora, 2008).

Perception of effort (RPE), otherwise known as perceived exertion or sense of effort (Marcora, 2009), has been defined as the conscious sensation of how hard heavy or strenuous a physical task is (Borg, 1998; Marcora, 2010). Previously, this measure of RPE has been obtained using a modified Borg Scale (Marcora, Bosio, & de Morree, 2008, Marcora & Staiano, 2010). In addition to this subjective rating based evaluation, psychophysiological measures have also been utilized in order to provide an objective evaluation of effort. Principally, facial electromyography (EMG) was originally used to quantify mental effort (Capa, Audiffren, & Ragot, 2008; Silvestrini & Gendolla, 2009). Accordingly, it has also recently been implemented in physical tasks by obtaining the EMG amplitude of the bilateral corrugator supercilii as individuals performed leg extension tasks under different loads (de Morree & Marcora, 2010) or cycled to exhaustion (de Morree & Marcora, 2012). Presently this research has found that facial EMG increases significantly with RPE and task difficulty during leg extension exercise (de Morree & Marcora, 2010). The findings during constant intensity cycling exercise were more equivocal however (de Morree & Marcora, 2012) with a significant increase in facial EMG accompanying the increase in RPE at an intensity corresponding to 80% PPO, but not at a lower intensity (63% PPO). While promising, the use of this measure during endurance tasks therefore requires further investigation.

The subjective measurement of RPE is a feature of many endurance based exercise studies (Crewe, Tucker, & Noakes, 2008; Doherty & Smith, 2005; Faulkner, Parfitt, & Eston, 2008; Marcora et al, 2008; Parry, Chinnasamy, & Micklewright, 2012). In open loop studies, which are defined by the absence of a known endpoint (Coquart & Garcin, 2008), RPE consistently increases with time on task (Marcora et al., 2008; Faulkner et al., 2008; Noakes, 2010). Furthermore, when open loop studies require the participant to exercise to exhaustion at a fixed workload, task termination coincides with a maximum or near maximum RPE (Jacobs & Bell, 2004; Marcora & Staiano, 2010; Presland et al., 2005). This remains the case when RPE is experimentally manipulated, for instance by altering environmental temperatures (Crewe et al., 2008; see Figure 1.3) or inducing pre-exercise muscle damage (Marcora at al., 2008), and regardless of whether this causes an increase (Jacobs & Bell, 2004) or a decrease in exercise task duration (Marcora et al., 2009). Consequently, some researchers conclude that it this maximum RPE that causes the individual to consciously terminate exercise (Marcora 2009; Presland et al., 2005; Sgherza et al., 2002). Similarly, in closed loop studies which consist of a self-regulated exercise intensity towards a known endpoint (Marino, 2012), individuals are suggested to continually adjust their pacing in order to maintain an RPE that permits them to complete the task (Marcora, 2008). This is evident when an intervention causes a change in RPE, such that individuals are compelled to reduce their workload in order to sustain a given RPE (de Morree & Marcora, 2012), or individuals are able to achieve a higher workload for an equal RPE (Bell, McLellan, & Sabiston, 2002). For each of these reasons RPE is considered to be a pivotal determinant of physical endurance (Marcora, 2009).

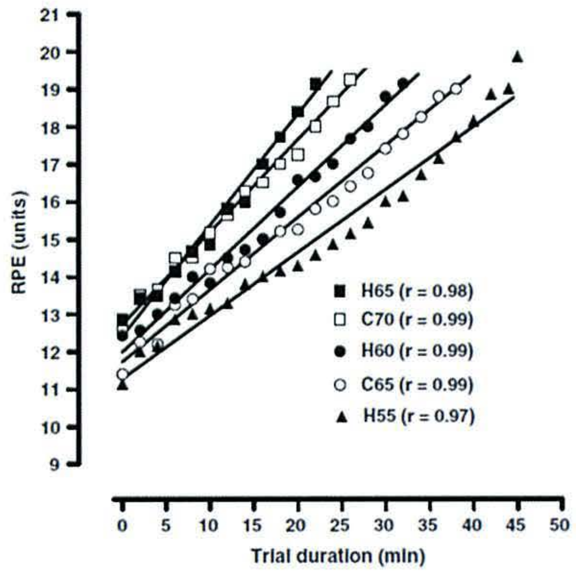

Figure 1.3. RPE increases throughout exercise until reaching maximum at exhaustion. This is regardless of experimental treatment or the duration of the task (Crewe at al., 2008).

Debate currently exists surrounding the way that RPE is generated. Some researchers contend that RPE is a product of involuntary peripheral changes that take place within the working muscles during exercise (MacIntosh and Shahi, 2011b), or the integration of afferent signals from group III and IV afferent receptors within the heart, muscles and lungs (Amann & Secher, 2009). Others suggest that RPE is determined by a combination of these afferent signals and psychological cues (Eston et al., 2007) while it has also been proposed that factors such as core temperature and fuel stores combine with afferent signalling to generate RPE and protect the organism from catastrophic disturbances in homeostasis (Noakes, 2012).

Conversely, there is evidence to suggest that RPE is produced independently of afferent feedback from the heart, muscles and lungs (Marcora, 2009). In this regard, RPE is instead proposed to be generated by the sensory areas of the brain from an efference copy of central motor command (Marcora, 2009). Recent support for this proposal has been provided by de Morree and Marcora (2012) who found that the amplitude of movement related cortical potentials during movement execution correlates with RPE. Hence, RPE may represent the conscious sensory awareness of central motor command during physical work.

Importantly other neural structures, and various neurotransmitters, have also been associated with effort. Hence it is possible that perception of the sensory signal of effort arising from central motor command can be altered. In support of this the anterior cingulate cortex (ACC) has been associated with effort and effort based decision making in rodents and in humans. For instance rodents with ACC lesions forego larger rewards for less effortful options (Hillman & Bilkey, 2010) while humans with similar lesions report a loss of will (Mulert, Menzinger, Leicht, Pogarell, & Hegerl, 2005). Moreover, insular cortex activity is altered when the sense of effort is hypnotically manipulated (Williamson et al., 2001). In addition to these neural structures, the neurotransmitter dopamine appears to alter effort (Denk et al., 2005; Jacobs & Bell, 2004), as do endogenous opioids (Sgherza et al., 2002). These findings are relevant as they indicate that implementing specific psychological and psychobiological interventions to alter the way that effort is consciously perceived may provide a basis for modifying, or exceeding, individual endurance limits. Hence, such approaches may represent possible strategies for endurance performance enhancement.

1.7. Motivational Intensity Theory

As illustrated by the associations between RPE and physical endurance, it is recognised that effort is necessary to overcome obstacles and deterrents (Gendolla & Richter, 2010). In addition, effort is suggested to be subject to the conservation principle; therefore individuals will not invest more effort than necessary to fulfil a given task (Wright, 2008). This interplay between effort investment and task performance is signified by motivational intensity theory (Brehm & Self, 1989). This theory predicts that effort is proportional to the perceived difficulty of the task providing that the demands of the task are viewed as worthwhile and possible. Consequently, an individual will persist with a task until they reach the maximum amount of effort that they are willing to invest in the task (i.e., potential motivation) or until they reach the point at which continuation in the task seems to be impossible (see Figure 1.4). Upon reaching either of these points, effort is withheld and voluntary task disengagement occurs.

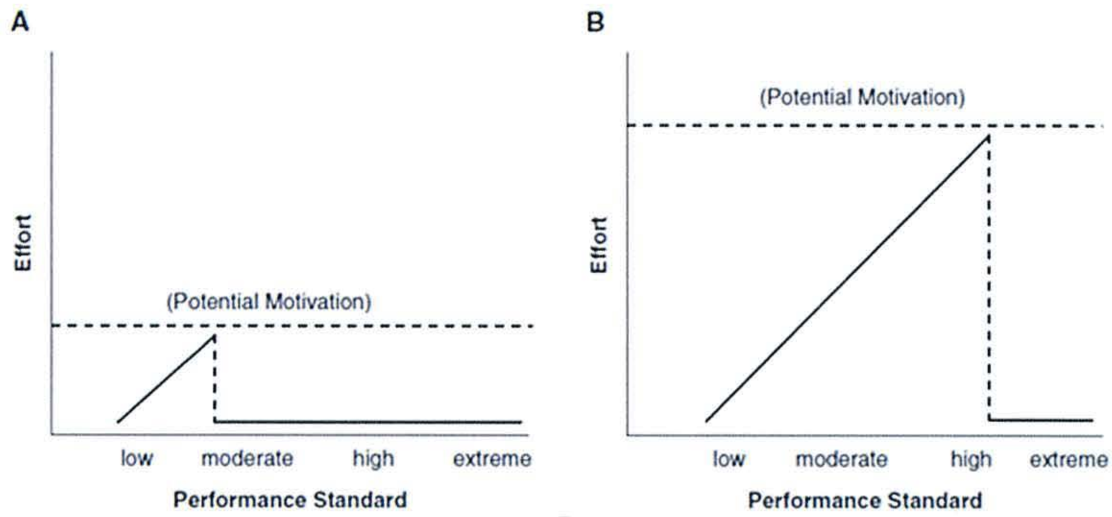

Figure 1.4. Predictions of motivational intensity theory: An individual will persist with a task until they reach the maximum amount of effort that they are willing to invest in the task in order to succeed (A) or until continuation in the task appears impossible (B). Upon reaching either point effort is withheld and task disengagement occurs (Gendolla & Richter, 2010).

The principles of motivational intensity theory are consistent across a variety of situations. This includes situations relating to mood, perceived ability, fatigue, and incentive. Specifically, when any of these factors are altered, the point at which effort is withheld is seen to vary. For example, individuals who possess high perceived ability on a task invest a high level of effort under conditions of elevated task difficulty. In contrast, individuals with a low perceived ability withhold effort much more readily at the same level of task difficulty (Wright & Dill, 1993). Moreover, the opposite is true at low levels of task difficulty whereby individuals with low perceived ability invest more effort than their high perceived ability counterparts (Wright & Dismukes, 1995). The same finding occurs for different states of fatigue such that individuals experiencing a high state of fatigue withhold effort more readily under difficult task conditions than those who are not fatigued (Wright, Shim, Hogan, Duncan, & Thomas, 2012) but invest greater effort than the same individuals when task conditions are easier. Equally, Gendolla and Krüsken (2002) reported that individuals in a positive mood more readily invest effort under difficult task conditions. This is in comparison to those in a negative mood who withhold effort more easily (see Figure 1.5). This finding has also been replicated when moods are manipulated subconsciously, suggesting that effort related processes can be altered through non-conscious means (Freydefont, Gendolla, & Silvestrini, 2012; Gendolla & Silvestrini, 2011). Considering the important role played by effort during physical endurance tasks, the links between perceived task demand, task disengagement, and psychological / psychobiological factors that arise from motivational intensity theory therefore has important implications for physical endurance.

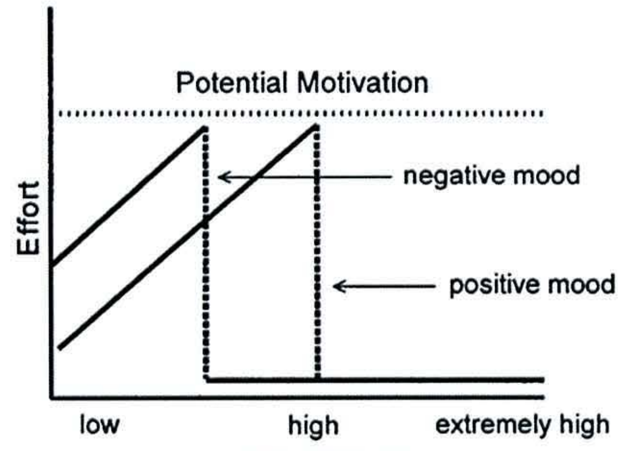

Figure 1.5. Individuals in a negative mood invest more effort under conditions of low task difficulty and withdraw effort more readily as task difficulty increases in comparison to individuals in a positive mood (Gendolla & Krüsken, 2002).

1.8. The Psychobiological Model of Endurance Performance

The basis of motivational intensity theory (Brehm & Self, 1989; Wright, 2008) has recently been incorporated into a model of endurance performance. This is to provide an empirical conceptualization of the way that RPE effects physical endurance. This model, the psychobiological model of endurance performance (Marcora, 2008), proposes that exercise related exhaustion is signified by a conscious and voluntary decision to terminate a task (Marcora, 2008). This is in contrast to the perspective of physiological muscle fatigue in which exhaustion is thought to represent involuntary task failure due to muscle impairment (Allen et al., 2008; MacIntosh & Shahi, 2011a). According to the psychobiological model of endurance performance, the conscious and voluntary decision to terminate a task depends on two factors; the potential motivation of the individual, and the amount of effort that is perceived by the individual during the task (Marcora, 2008). Consequently, voluntary task termination occurs because either the effort required by the task exceeds the maximum amount of effort that the individual is willing to exert in order to succeed in the task, or because the amount of effort required by the task becomes so great the individual perceives task continuation as impossible (see Figure 1.6). As such, the psychobiological model of endurance performance predicts that any physiological or psychological factor affecting RPE will affect endurance performance (Marcora et al., 2008).

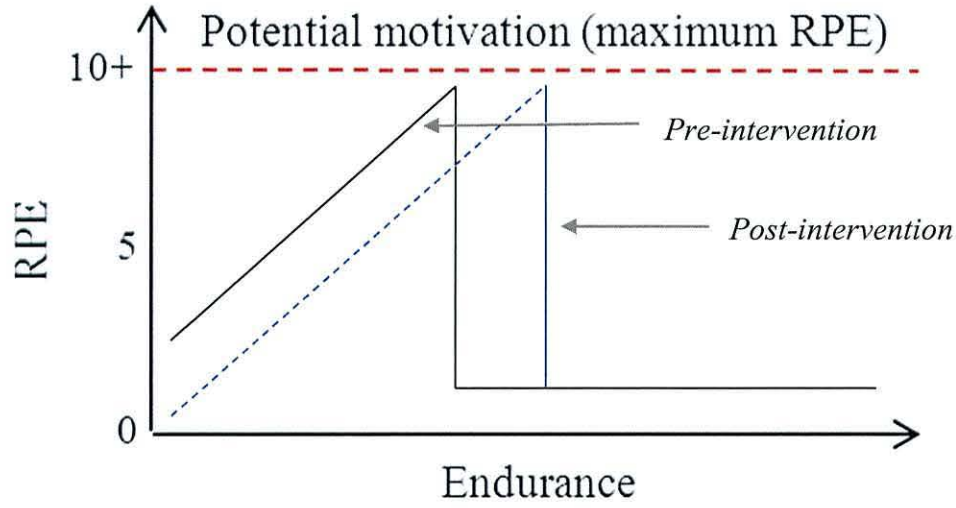

Figure 1.6. The psychobiological model of endurance performance. Any post-intervention reduction in RPE (blue line) will delay voluntary task termination and enhance endurance.

Support for the psychobiological model of endurance performance can be obtained from a variety of psychological, psychobiological and physiological studies of physical endurance. In open loop studies for example, the reduction in physical endurance that was reported following ninety minutes of mentally fatiguing activity (Marcora et al., 2009) is thought to have occurred due to the negative impact of mental fatigue upon RPE. To explain this, Marcora et al. (2009) suggested that onset of mental fatigue increased RPE during the task hence maximum RPE was reached sooner, influencing individuals to voluntarily terminate the task earlier. This also appears to be the case following sleep deprivation (Martin, 1981) whereby attenuated endurance following 36 hours of sleep deprivation occurred alongside an elevated RPE which was proposed to have influenced individuals to voluntarily withdraw from the task sooner. Along with these findings, administration of the opioid antagonist naloxone was found to elevate RPE while cycling to exhaustion during a maximal exercise test (Sgherza et al., 2002). Moreover it was suggested by the authors that the elevation in RPE caused participants to disengage from the task sooner. In contrast, ingestion of the psycho-stimulant modafinil caused a significant reduction in RPE while cycling to exhaustion at 85% $\dot{V}O_{2max}$ (Jacobs & Bell, 2004). Again, according to the authors, this delayed the point at which RPE reached maximum values, permitting participants to cycle for 28% and 17% longer than the control and placebo conditions respectively. As such, the reduction in RPE was deemed to be the key factor in this increased cycling capacity (Jacobs & Bell, 2004). Similar findings have also been established following ten weeks of respiratory muscle training whereby a significant increase of 36% in cycling capacity was accompanied by a significant reduction in RPE (Gething, Williams, & Davies, 2004). Furthermore, Okano et al. (2013) have recently reported that transcranial direct current stimulation increased peak power output by 4% in conjunction with a reduction in RPE during maximal exercise.

Comparable support for the psychobiological model of endurance performance can also be found in closed loop interventions. For instance pre-exercise induced locomotor muscle fatigue reduced the total work completed by 4.8% in a 15 minute time-trial despite no significant differences in RPE after the first 3 minutes of the task (de Morree & Marcora, 2012). This indicates that participants reduced their power output at an absolute level of RPE following locomotor muscle fatigue to ensure that they could complete the time-trial and avoid prematurely reaching maximal effort. Likewise, when RPE was held constant during self-paced cycling following ninety minutes of prior mental fatigue, once more participants were forced to reduce their power output in order to maintain a given level of RPE (Brownsberger et al., 2013). Conversely, Parry et al. (2012) have reported that manipulating optic flow elicited a reduction in RPE and an increase in power output when individuals perceived their surroundings to be moving more slowly as they cycled. Moreover, caffeine plus ephedrine consumption has been found to reduce 10 km run time compared to placebo despite no statistical differences in RPE (Bell et al., 2002), while mouth rinsing with a carbohydrate solution reduced the time required to complete a set amount of work; once more despite no change in RPE (Carter, Jeukendrup, & Jones, 2004). Hence in these latter cases, participants were able to produce more physical work for a lower or equal RPE.

1.9. Open Loop and Closed Loop Endurance Tasks

As already indicated, open loop tasks require the maintenance of a set workload for an indefinite amount of time. The end point in open loop tasks is therefore unknown (Coquart & Garcin, 2008). In closed loop tasks the end point is generally known and pre-designated, requiring a certain quantity of work to be carried out in a given amount of time, or a specified distance to be covered as quickly as possible (Marino, 2012). As such, closed loop tasks therefore permit self-regulated pacing in order to fulfil the task criteria. In contrast, open loop tasks are generally performed to exhaustion, in many cases at a constant exercise intensity.

Perhaps the most commonly used closed loop task is the laboratory based time-trial test. Moreover the most commonly used open loop task is the constant intensity time to exhaustion (TTE) test. Some authors have suggested that the use of time-trial based closed loop tasks are more preferable than constant intensity open loop tasks such as the TTE test due to their greater reliability and hence sensitivity to detect changes in performance (Jeukendrup & Currell, 2005). Specifically the larger coefficient of variation (CV) that is inherent in TTE tests, compared to time-trial tests, is assumed to mask any genuine changes in endurance performance. For example, TTE tests have been reported to have a CV of 26.6% in comparison to a CV of 3.4% in time-trial tests (Jeukendrup, Saris, Brouns, & Kester, 1996). This assumption however does not consider that the change in performance following an intervention is also generally larger in TTE tests than time-trial tests (Hopkins, Schabort, & Hawley, 2001). Accordingly, recent research has in fact demonstrated a similar sensitivity between TTE tests and laboratory based time-trial tests (Amann, Hopkins, & Marcora, 2007).

This is because the relatively large change in performance that is associated with TTE tests cancels out their high CV, making the signal to noise ratio between measurement error and changes in physical endurance statistically comparable to time-trial tests.

Despite their equal sensitivity to time-trial tests, constant intensity TTE tests have been criticised by some authors who have suggested that they lack ecological validity in comparison to closed loop tasks such as time-trial tests (Jeukendrup & Currell, 2005; Marino, 2012). This is because constant intensity TTE tests disregard individual pacing and because their format does not emulate any known athletic event (Marino, 2012). Although these concerns are relevant, TTE tests are essential to the investigation of physical endurance for two reasons. Firstly, implementing an exhaustive test is the only way in which the factors that limit physical endurance can be satisfactorily investigated; this is important if the factors that pertain to exhaustion in both a social and sporting context are to be experimentally clarified. Secondly, such tests are able to more efficiently isolate the effect of a specific independent variable on physical endurance. This is primarily because the constant intensity of TTE tests can somewhat clamp the potentially confounding physiological influences that may arise from self-regulated pacing during time-trial tests (Maughan, 2012). Such a consideration is important when measuring the effect of a novel intervention on a psychobiological variable such as RPE. Particularly, since RPE has been associated with a number of physiological influences (Amann et al., 2008; MacIntosh & Shahi, 2011b), it is important to mitigate the potential impact of these physiological influences across visits. This allows the isolated effect of a psychological or psychobiological intervention on RPE and / or the limitations to physical endurance to be more precisely determined.

While time-trial tests therefore arguably deliver greater ecological validity, they are less equipped to provide the control that is required to establish the effects of novel psychological or psychobiological interventions on the limits to endurance. Consequently, the implementation of constant intensity TTE tests or time-trial tests is dependent on the research question. Succinctly, if the purpose is to investigate pacing then a time-trial test should be selected. Alternatively, if the purpose is to isolate the effect of a specific variable on the limits to endurance then a constant intensity TTE test should be selected (Marino, 2012). TTE tests therefore permit a strong proof of principle foundation from which time-trial based interventions can be later investigated.

1.10. Aim of the Thesis

Based on the proposition that RPE acts as a pivotal determinant of endurance performance (Marcora, 2009), the general aim of this thesis was to establish whether specifically selected psychological or psychobiological interventions were able to directly target and alter RPE in order to modify the limits to physical endurance. In conjunction with this, the thesis sought to identify whether these proof of principle interventions may provide a basis for novel psychological or psychobiological performance enhancing strategies within the framework of the psychobiological model of endurance performance (Marcora, 2008; Marcora, 2009). To accomplish this, the aims of each experimental chapter were as follows:

The aim of Chapter 2 was to implement a two week protocol motivational self-talk in order to assess whether this psychological intervention was able to reduce RPE and enhance physical endurance.

The aim of Chapter 3 was to implement a novel 6 week cognitive training programme to assess whether repeatedly targeting a neural structure that is associated with cognitive and physical effort could elicit a reduction in RPE and enhance physical endurance.

The aim of Chapter 4 was to assess whether implicit affective cues presented outside of conscious awareness were able to alter RPE and accordingly modify physical endurance.

This chapter was constructed to establish if a basis existed for future performance enhancing interventions within the context of implicit affective priming.

The aim of Chapter 5 was to assess whether subliminally primed action and inaction words were able to alter RPE during an exhaustive task and consequently modify physical endurance. This chapter was also designed to illustrate the use of randomizations tests as an experimental approach to single subject research.

1.11. Outline of the Thesis

Other than the general introduction and the general discussion, this thesis contains four experimental chapters (Chapters 2-5). These chapters have been written as independent papers with the purpose of publication in peer-reviewed journals. Necessary overlap will therefore exist at times within the contents of these chapters. Figures and tables are numbered in conjunction with the chapter in which they are included and abbreviations are defined by their first appearance in each chapter. This is in accordance with the list of abbreviations included at the beginning of the thesis.

In order to conform to recommendations by the American Psychological Association (APA, 2010, p. 34), multiple degree of freedom effects have been decomposed into single degree of freedom effect sizes in standardized units (Cohen, 1988) where relevant. Precision of the estimate has been expressed with the use of a priori confidence intervals. Magnitude based inferences (Batterham & Hopkins, 2006) have also been implemented in Chapters 2, 3, and 4 to provide a measure of practical significance where this informs the discussion.

CHAPTER 2

Talking Yourself out of Exhaustion: The Effects of Motivational Self-Talk on RPE and Physical Endurance [1,2]

[1]This chapter is accepted for publication as:

Blanchfield, A. W., Hardy, J., Staiano, W., de Morree, H. M., & Marcora, S, M. (2013). Talking Yourself out of Exhaustion: The Effects of Self-Talk on Endurance Performance. *Medicine and Science in Sports and Exercise*, Advance online publication.

[2]A section of this research was presented at the BASES student conference 2011

2.1 Abstract

Purpose: The psychobiological model of endurance performance proposes that perception of effort (RPE) is the ultimate determinant of endurance performance. Therefore, any physiological or psychological factor affecting RPE will affect endurance performance. Accordingly this study investigated the effects of a frequently used psychological strategy, motivational self-talk (ST), on RPE and cycling time to exhaustion (TTE). **Method**: In a randomized between groups pre-test – post-test design, 24 participants (mean ± SD age 24.6 ± 7.5 years; $\dot{V}O_{2max}$ 52.3 ± 8.7 $ml \cdot kg^{-1} \cdot min^{-1}$) performed two constant-load (80% peak power output) TTE tests. These were punctuated by a two week ST intervention or a control phase. **Results**: Group (ST vs. Control) x Test (Pre-test vs. Post-test) mixed model ANOVA's revealed that ST significantly enhanced TTE from pre-test to post-test (637 ± 210 s vs. 750 ± 295 s, $p < .05$) with no change in the control group (486 ± 157 s vs. 474 ± 169 s). This equated to a *very likely beneficial* practical effect of motivational self-talk on TTE (beneficial/trivial/harmful%; 99/1/0%). Moreover, a Group x Test x Iso-time (0%, 50%, 100%) mixed model ANOVA revealed a significant interaction for RPE. Follow-up tests indicated that motivational self-talk significantly reduced RPE at 50% iso-time (7.3 ± 0.6 vs. 6.4 ± 0.8, $p < .05$), with no significant difference in the control group (6.9 ± 1.9 vs. 7.0 ± 1.7). Practically this effect was *very likely beneficial* (98/2/0). **Conclusion**: This study is the first to demonstrate that ST significantly reduces RPE and enhances TTE. The findings support the psychobiological model of endurance performance and illustrate that psychobiological interventions designed to specifically target favorable changes in RPE are beneficial to endurance. Consequently this psychobiological model offers an important and novel perspective for future research investigations.

Descriptors: Perception of effort, psychobiological model, iso-time, psychological strategy

2.2. Introduction

The popularity of endurance sports in recent decades has coincided with a substantial growth in the number of individuals taking part in endurance based events. As such, the use of performance enhancing strategies is relevant for many competitors when training or taking part in these events. A key aspect of performance in most endurance sports is the ability to sustain aerobic exercise over prolonged periods. The upper limit to this ability, commonly referred to as exhaustion, is traditionally proposed to represent the end point of involuntary and progressive muscle fatigue (Allen, Lamb, & Westerblad, 2008; Amann et al., 2011). Consequently, strategies designed to enhance the performance of endurance competitors frequently target the musculo-energetic and cardio-vascular elements of endurance (Joyner & Coyle, 2007).

Alternatively, the psychobiological model of endurance performance (Marcora, Staiano, & Manning, 2009; Marcora & Staiano, 2010), based on motivational intensity theory (Brehm & Self, 1989) posits that exhaustion is caused by the voluntary decision to terminate endurance exercise, as opposed to muscle fatigue (Marcora et al., 2009). As such, an individual will terminate exercise either when the effort required by the task exceeds the greatest amount of effort that the individual is willing to exert during the task (i.e., potential motivation), or when maximum effort is considered to have been reached and continuation of the task is perceived as impossible (Marcora et al., 2009; Marcora & Staiano, 2010).

According to this psychobiological model, a major determinant of endurance performance in highly motivated subjects is perception of effort (RPE); defined as the conscious sensation of how hard, heavy and strenuous exercise is (Marcora, 2010). Therefore, it is predicted that any physiological or psychological factor affecting RPE will affect endurance performance (Marcora et al., 2008; Marcora et al., 2009). In support of this perspective, interventions such as sleep deprivation (Martin, 1981), naloxone administration (Sgherza et al., 2002), and mental fatigue (Marcora et al., 2009) have been shown to elevate RPE and hinder endurance performance, whereas interventions such as physical training (Ekblom & Golobarg, 1971), nutritional intake (Blackhouse, Bishop, Biddle, & Williams, 2005) and psycho-stimulant manipulations (Doherty & Smith, 2005; Jacobs & Bell, 2004) have been shown to reduce RPE and enhance endurance performance. The enhancement of physical endurance through strategies that specifically target a reduction in RPE is therefore appealing. To date however, the scope of strategies that are designed for this purpose remains narrow. Moreover, other than the effects of music (Karageorghis, & Lee-Priest, 2012) and associative/dissociative attentional techniques (Lind, Welch, & Ekkekakis, 2009), the exploration of psychological strategies within this context seems minimal. The identification of psychological strategies that are able to reduce RPE and enhance physical endurance therefore warrants further investigation.

One widely used psychological strategy that has been postulated to favor effort based tasks is self-talk (Hardy, Gammage, & Hall, 2001). Self-talk has been defined as a multidimensional phenomenon concerned with athletes' self-addressed verbalizations that can serve both instructional and motivational functions (Gammage, Hardy, & Hall, 2001). This definition is based on the results of qualitative data analyses revealing that self-talk can be broadly categorized as instructional or motivational (Hardy et al., 2001). Moreover, motivational self-talk employed during exercise can be further divided into the auxiliary components of arousal, mastery, and drive (Gammage et al., 2001).

It has been noted that the effort oriented motivational drive function represents the most frequently reported reason for the use of self-talk during exercise. This is most prevalent towards the end of the workout when the desire to terminate exercise is at its strongest (Gammage et al, 2001). As such, it has been proposed that motivational self-talk should be effective at not only enhancing motivation but at regulating effort (Hardy et al., 2001). Corresponding to the psychobiological model of endurance performance, this suggests that motivational self-talk might be an effective psychological strategy for the enhancement of physical endurance. To date however, many studies that have investigated the use of self-talk during endurance based tasks have done so using psychological skills packages (Barwood, Thelwell & Tipton, 2008; Thelwell & Greenlees, 2001). As acknowledged by these investigations, this makes the precise benefit of individual components such as self-talk difficult to evaluate. Despite this, post-experimental questionnaires have indicated that participants find self-talk to be an effective psychological strategy (Barwood et al., 2007). Even so, very few studies have explored the effects of self-talk upon physical endurance in isolation. Furthermore, no investigation has experimentally examined the effects of motivational self-talk upon RPE during endurance exercise. For example, it has been found that assisted positive self-talk, self-regulated positive self-talk, and assisted negative self-talk each enhanced work output during 20-min cycling exercise (Hamilton, Scott, & MacDougall, 2007). Nonetheless, the multiple baseline single-subject design did not implement statistical analysis thus making the findings challenging to interpret and generalize. Furthermore, physiological and perceptual measures were lacking, hence it is challenging to determine the mechanisms behind the enhanced work output. Similarly, the effect of self-addressed verbalizations upon performance has been investigated at specific points during a marathon (Schuler & Lagens, 2007). However, despite finding that self-addressed verbalizations correlated with improved performance, once more physiological and perceptual measures were lacking. Moreover, the non-experimental nature of this study makes it difficult to establish a causal relationship between the use of self-talk and improved endurance.

The aim of the present study was to experimentally investigate the effect of motivational self-talk on physical endurance during high-intensity cycling exercise. A time to exhaustion (TTE) test was selected as this has been shown to be a sensitive measure of endurance performance (Amann, Hopkins, & Marcora, 2007). Furthermore, perception of effort was measured using RPE and a recently developed psychophysiological measure based on the facial expression of effort (de Morree & Marcora, 2010). It was hypothesized that motivational self-talk would reduce RPE during high-intensity cycling exercise and that this would increase TTE.

2.3. Method

2.3.1. Participant Characteristics and Ethics

Twenty four recreationally trained individuals (15 male & 9 female); [mean ± *SD*, age 24.6 ± 7.5 years; height 176 ± 7 cm; weight 72.7 ± 10.1 kg; peak power output (PPO) 313 ± 69 W; maximum oxygen uptake ($\dot{V}O_{2max}$) 52.3 ± 8.7 ml·kg^{-1}·min^{-1}] volunteered to take part in the study. All participants were healthy, free from injury, and engaged in a range of individual or team based aerobic sports on at least two occasions per week with an average session duration of 83.3 ± 29.3 minutes. The study was approved by the ethics committee of the School of Sport, Health and Exercise Sciences, Bangor University. Prior to taking part, all participants completed an informed consent form and a standard medical questionnaire to confirm their present state of health. Participants were also provided with an overview of all procedures and requirements of the study prior to its commencement but remained naive to the aims and hypotheses. Upon cessation of the study, participants were debriefed and were requested not to discuss the study with other individuals.

2.3.2. Study Design and Procedures

The study consisted of a single-blind, controlled, pre-test – post-test design in which participants visited the laboratory on three separate occasions and were randomized into two independent groups (n = 12) after the second visit. The control group contained 7 males and 5 females while the self-talk group contained 8 males and 4 females. All exercise tests were conducted in the same location on the same electromagnetically braked cycle ergometer (Excalibur Sport, Lode, Groningen, the Netherlands). Saddle and handlebar specifications were adjusted to suit the preference of each subject and maintained for each visit. During Visit 1 all participants first completed an informed consent questionnaire and an instruction checklist, after which anthropometric measurements were recorded. An incremental test was then carried out to establish PPO and $\dot{V}O_{2max}$. The incremental test began with a two minute rest after which power output was increased by 50 W every two minutes until volitional exhaustion. Exhaustion was operationally defined as a reduction in cadence below 60 revolutions per minute (RPM) for 5 consecutive seconds despite strong verbal encouragement. For the incremental test, the cycle ergometer was set in hyperbolic mode, which allows the power output to be set independently of cadence over a range of 30-120 RPM. The participant was instructed to remain in the saddle at all times during the test. $\dot{V}O_{2max}$ was measured breath by breath via a computerized metabolic gas analysis system (Metalyzer 3B, Cortex Biophysik, Leipzig, Germany) connected to an oro-(mouth) mask (7600 series, Hans Rudolph, Kansas City, MO). The device was calibrated before each incremental test using a known concentration of gases and a 3.0 liter calibration syringe (Series 5530, Hans Rudolph). PPO was calculated according to the equation of Kuipers, Verstappen, Keizer, Geurten, and van Kranenburg (1985). Resting heart rate was recorded 15 seconds from the end of the two minute rest using wireless chest strap radio telemetry (S610, Polar Electro, Kempele, Finland) and was then measured every minute during the incremental test thereafter. RPE was also recorded every minute during the incremental test using the CR10 scale (see Perceptual and psychophysiological measures of effort).

During Visit 2, participants first completed an instruction checklist followed by separate mood and motivation questionnaires (see Psychological questionnaires). Following this, participants performed a TTE test. For the TTE test, participants were positioned on the cycle ergometer (set to hyperbolic mode) and instructed to remain in the saddle at all times. The TTE test commenced with a three minute warm up at 40% PPO. After three minutes, the power output was automatically increased to 80% PPO. Cadence was freely chosen between 60 – 100 RPM and was recorded each minute during the test. RPE was also recorded every minute using the Borg CR10 scale along with heart rate (see Additional physiological measures). Bipolar single differential surface electromyography (EMG) was recorded from the corrugator supercilii throughout (see Perceptual and psychophysiological measures of effort). TTE was defined as the time accrued from the start of exercise at 80% PPO until either cadence had fallen below 60 RPM for five consecutive seconds, or participants voluntarily stopped. No verbal encouragement was provided at any point during the TTE test to eliminate the superimposition of any extraneous verbal statements. A fan was placed approximately 60 cm in front of the cycle ergometer. Participants were given the option of exercising with or without the fan and completed the subsequent TTE test under identical conditions. To avoid bias from mimicry and audience effects upon facial EMG, the experimenter stood behind participants at all times (Tassinary, Cacioppo, & Vanman, 2007). Three minutes after test cessation, participants provided a blood sample for lactate analysis (see Additional physiological measures). Random group allocation then took place (www.randomization.com) with participants who were allocated to the self-talk group carrying out a two-stage intervention over the ensuing two weeks (see Motivational self-talk intervention) and participants allocated to the control group receiving no intervention. Both groups continued their usual aerobic exercise regime during this two week period.

All testing procedures carried out during Visit 2 were replicated during Visit 3; participants in the self-talk group were reminded to make use of their four self-talk statements during the TTE test. At the end of Visit 3, participants completed a manipulation check questionnaire (see Manipulation checks) and remained naive to their cycling times until the debriefing that followed the manipulation checks.

Visits 1 and 2 were separated by a minimum of 72 hours, while Visits 2 and 3 were punctuated by a minimum of 14 days, during which the motivational self-talk intervention (self-talk group) or usual exercise without the self-talk intervention (control group) took place. All participants visited the laboratory at a similar time of day for each of their visits. As instructed before each visit, participants maintained similar dietary patterns during the preceding 24 hours while consuming an amount of water equivalent to least 35 $ml \cdot kg^{-1}$ body weight and attaining at least 7 hours of sleep the night before. Participants also avoided any heavy exercise in the 24 hours prior to testing and refrained from the consumption of caffeine and nicotine in the 3 hour period leading up to each test. Finally, participants voided before each test and performed during all visits in similar clothing.

2.3.3. Motivational Self-talk Intervention

Similar to Thelwell and Greenlees (2001), the motivational self-talk intervention was administered in two stages and involved the use of a workbook (see Appendix A). Stage 1 occurred after the first TTE test (pre-test), and comprised of a 30 minute introduction to self-talk along with the identification and development of four motivational self-talk statements. Stage 2 consisted of the practical use of these statements during their customary aerobic exercise sessions throughout the two week intervention. This format was used to facilitate the personalized and practiced use of each statement.

During Stage 1, participants were introduced to the concept of self-talk and provided with a workbook in which they highlighted any self-talk statements that they had used in the preceding TTE test. From this pool of self-statements, participants identified up to five that were deemed to be motivational and compared them to a set of 12 pre-listed motivational statements (e.g., *drive forward*, *you're doing well*) generated from the existent self-talk literature. From these two lists participants were requested to select four statements that would optimize their performance during a TTE test identical to the one previously carried out. It was instructed that two of these statements should be relevant to the early-mid stage of such test (e.g., *feeling good*) with the remaining two being more applicable to the last point of the test near exhaustion (e.g., *push through this*). This approach was chosen to identify the contextual influence of verbal statements (Landin, 1994) upon specific stages of the TTE test.

Stage 2 was a familiarization phase in which participants were instructed to use their selected statements during a minimum of three self-administered aerobic exercise sessions over the two week period. After each aerobic exercise session, participants completed a workbook protocol to help in assessing the efficacy of their four chosen statements used during the session. Effective statements were noted and employed in the subsequent aerobic exercise sessions; ineffective statements were either re-phrased or replaced with a more suitable statement (as deemed by the participants). This process was designed to ensure that participants were comfortable using their four motivational self-statements when they performed the second TTE test (post-test).

2.3.4. Manipulation Checks

Following the second TTE test (post-test), each participant completed a questionnaire based manipulation check. For both groups, this manipulation check assessed adherence to their respective manipulation instructions on an 11-point Likert type scale (0 = *not at all*, 10

= *greatly*). The remainder of the manipulation check questionnaire was specific to each group. The manipulation check for the self-talk group was designed to measure the extent of self-talk usage during the TTE test (see Appendix B). The manipulation check for the control group was designed to disclose any use of self-talk during the TTE test. If participants in the control group used some form of self-talk, space was allocated to reveal each statement used along with its extent of use. This was measured on an 11-point Likert type scale (0 = *rarely*, 10 = *very often*). For the self-talk group, space was allocated to highlight each motivational self-talk statement that they had used during the TTE test, both designated and undesignated. Again the extent of use for each statement was also indicated.

2.3.5. Perceptual and Psychophysiological Measures of Effort

RPE was measured using the modified 11-point CR10 scale developed by Borg (1998). Low (0.5 = *very, very light*) and high (10 = *maximum*) anchors were established using standard procedures (Noble & Robertson, 1996). Participants were also free to rate a value above 10 if they perceived their state of effort to be higher than any previous maximal effort experienced. Standardized instructions for perceived effort were provided to all participants prior to each test with the emphasis that each rating should be based upon the effort required to perform the TTE test as opposed to any muscle pain occurring during the test (see Appendix C).

Facial EMG has been shown to be a valid psychophysiological measure of perceived effort during a TTE test of similar exercise intensity to the one used in this study (de Morree & Marcora, 2012). Therefore bipolar single differential surface facial EMG amplitude was recorded from the left and right corrugator supercilii muscles throughout the TTE test. Prior to electrode placement the site above the brows was cleaned with an alcohol swab and the skin carefully dried with a tissue. On each side of the face, one pre-gelled Ag/AgCl electrode

(Neuroline 720-00-S, Ambu inc. Ølstykke, Denmark; recording area: ø 11 mm) was attached lateral to the glabellar midline. An additional electrode was attached immediately lateral to each of these placements just superior to the medial border of the eyebrow with a 40 mm inter-electrode distance (de Morree & Marcora, 2010). A ground strap was then placed around the wrist of the participant. The EMG signals were amplified by a multichannel EMG amplifier (EMG 16, OT Bioelettronica, Torino, Italy; Bandwidth: 10-500 Hz, 4th order Bessel low pass filter), fed into a 12-bit acquisition board (DAQCard-6024E, National Instruments Corporation, Austin, TX) at a sampling rate of 2048 Hz, displayed on a PC, and recorded for later offline analysis. Participants were unaware of the real purpose of the facial electrodes and were told that they were used to measure brain activity. EMG data were analyzed offline using Matlab version 7.12. The data were filtered with a zero-lag, bandpass, 4th order Butterworth filter (cutoff frequencies 20 and 400 Hz). The root mean square of the facial EMG data was calculated over 1-min periods.

2.3.6. Additional Physiological Measures

Heart rate was recorded throughout the TTE test using wireless chest strap radio telemetry (S610, Polar Electro, Kempele, Finland). Before testing, the chest strap was wetted and securely fastened to the participant's chest according to the manufacturer's guidelines. Lactate concentration was measured by collecting 5 μl of whole fresh blood from the earlobe three minutes after the TTE test. Each blood sample was immediately analyzed using a calibrated device (Lactate Pro LT-1710, Arkray, Shiga, Japan).

2.3.7. Psychological Questionnaires

The Brunel Mood Scale (BRUMS) was used to assess mood before each TTE test (see Appendix D). This abbreviated 24-item profile of mood states has been validated for use with adult populations (Terry, Lane, & Fogarty, 2003). This mood questionnaire includes six subscales (anger, confusion, depression, fatigue, tension, & vigor) with four items per subscale. Items were answered on a 5-point Likert type scale (0 = *not at all*, 1 = *a little*, 2 = *moderately*, 3 = *quite a bit*, 4 = *extremely*). Motivation was measured via the success motivation and intrinsic motivation scales developed and validated by Mathews, Campbell, and Falconer (2001). Each subscale consists of seven items on a 5-point Likert type scale with identical anchors to those described above (see Appendix E).

2.3.8. Statistical Analyses

Unless otherwise noted, data are shown as mean ± SD. After checking parametric assumptions, age, $\dot{V}O_{2max}$ and PPO were assessed for between group differences using independent *t*-tests. Manipulation checks were also assessed using independent *t*-tests to check for group differences in adherence to task instructions, number of self-talk statements used during the second TTE test (post-test), and also their mean extent of use. Group x Test multivariate analysis of variance (MANOVA) assessed for the effects of motivational self-talk on mood. A Group x Test analysis of variance (ANOVA) was carried out to assess for the effects of motivation, TTE, mean cadence, and various measures at exhaustion (RPE, facial EMG amplitude, heart rate, and blood lactate concentration). If assumptions of sphericity were violated the Greenhouse-Geisser correction was used while Tukeys HSD post hoc tests were calculated where appropriate. Group x Test x Iso-ime ANOVAs were used to test the effects of motivational self-talk on RPE, facial EMG amplitude, and heart rate at 0% (first minute), 50%, and 100% (final full minute completed) of TTE. These variables were measured at the selected time-points to allow the within-group comparison of temporal changes arising during the TTE test. In order to obtain this iso-time data, the value of each parameter at 100% iso-time was established by identifying the shortest TTE accomplished by each individual over their two tests. The value for each variable attained during the final full minute of the shortest TTE test was then compared to the value attained during the equivalent minute of the longer TTE test. The minute identified as 100% iso-time was divided by two and rounded up where necessary to attain the value corresponding to 50% iso-time. Iso-time values for 0% were attained by comparing values for the first full minute of each TTE test. Statistical significance was set at $p < 0.05$ (two-tailed) for all analyses and all data analysis was conducted using the statistical package for social sciences (SPSS version 16).

As null hypothesis significance testing is unable to convey the practical effect of an intervention, magnitude based inferences were also analyzed (Batterham & Hopkins, 2006). This indicated the practical effect of motivational self-talk on TTE, and at every measurement of iso-time RPE. The practical effect of motivational self-talk on TTE was established by firstly calculating the within participant change between the pre and post-intervention visits for each group. These mean changes were then subtracted to provide an overall difference in TTE between groups. This same procedure was implemented at each measured iso-time point to assess the practical effect of motivational self-talk on RPE. Standardized values of Cohen's *d* (Cohen, 1988) are provided as an estimate of effect size throughout.

Thresholds for small, moderate, and large effect sizes were set at 0.2, 0.5, and 0.8, respectively (Cohen, 1988). Precision of the estimate is provided by ± 90% confidence intervals (Hopkins, Marshall, Batterham, & Hanin, 2009). This indicates the plausible range within which the true population effect for each measure resides (Cumming, 2014). To assess the practical significance of each measure, the smallest worthwhile change between groups was based on a small effect size (>0.2) as recommended by Batterham and Hopkins (2006). The statistical likelihood of exceeding the smallest worthwhile change for each measure was calculated using a published spreadsheet (Batterham & Hopkins, 2006). Qualitative descriptors of the effect of motivational self-talk in relation to the smallest worthwhile change were assigned as follows: <1%; *almost certainly not*; <5% *very unlikely*; <25% *unlikely*; 25-75% *possible*; 75-95% *likely*; 95-99% *very likely*; >99% *almost certain*

(Batterham & Hopkins, 2006). Where the chance of benefit or harm were both >5%, the true effect was deemed *unclear*.

2.4. Results

2.4.1. Group Characteristics and Manipulation Checks

Age, $\dot{V}O_{2max}$ and PPO were not significantly different between groups (see Table 2.1), while the manipulation check questionnaire revealed that both groups adhered equally to their task instructions, $t(21) = -1.01$, $p = 0.32$. Given the nature of self-talk it is unsurprising that ten of the twelve participants in the control group reported limited use of self-talk. However, compared to the self-talk group, self-talk within the control group was used infrequently. The self-talk group used significantly more self-talk statements than the control group, $t(22) = -3.9$, $p = .001$ (4.1 ± 1.5 vs. 1.8 ± 1.4) and to a significantly greater extent, $t(15.48) = -2.16$, $p = .047$ (6.9 ± 1.4 vs. 4.9 ± 2.9). Motivational self-talk was therefore used differently and more extensively in the self-talk group compared to the control group.

Table 2.1. Mean ± SD of participant characteristics for the control group and self-talk group.

	Age (years)	$\dot{V}O_{2max}$ (ml·kg·min^{-1})	PPO (W)
Control (*n* = 12)	**25.0 ± 9.2**	**52.7 ± 8.7**	**306 ± 70**
Males (*n* =7)	28.7 ± 10.1	56.0 ± 8.7	352 ± 39
Females (*n* = 5)	19.8 ± 1.5	48.0 ± 7.8	241 ± 34
Self-Talk (*n* = 12)	**24.3 ± 6.2**	**51.8 ± 9.1**	**319 ± 72**
Males (*n* = 8)	25.4 ± 7.2	56.0 ± 6.0	361 ± 23
Females (*n* = 4)	22.0 ± 3.6	43.5 ± 9.0	236 ± 65
p value	= .81	= .82	= .65

Note. $\dot{V}O_{2max}$ (ml·kg·min^{-1}) = maximum oxygen uptake; PPO = peak power output; *p* value= overall difference between groups

2.4.2. Effects of Self-talk on Mood and Motivation Before the TTE Test

A Group x Test MANOVA revealed that participants in the motivational self-talk group and the control group commenced the TTE test during each visit in similar mood, as indicated by the fact that no Group x Test interactions, $F(2, 22) = 1.21$, $p = 036$ or main effects of test, $F(2, 22) = 0.70$, $p = 066$ were present for ratings on the BRUMS subscales. Univariate tests also revealed no differences on anysubscales (see Table 2.2). In addition, no Group x Test interactions or main effects of test were present for success motivation and intrinsic motivation with mean ratings for these scales signifying that participants in both groups were highly motivated to participate and perform well in the TTE test on both occasions.

Table 2.2. Mean ± SD ratings for BRUMS subscales and success and intrinsic motivation.

		BRUMS Subscales						Motivation	
		Anger	Confusion	Depression	Fatigue	Tension	Vigour	Success	Intrinsic
Pre	Con	0.7 ± 1.6	1.6 ± 2.4	0.3 ± 0.7	2.8 ± 1.9	2.7 ± 1.4	9.9 ± 3.2	20.6 ± 4.3	23.2 ± 2.9
	ST	0.8 ± 1.7	1.9 ± 3.0	0.9 ± 2.2	2.6 ± 2.2	2.9 ± 1.4	8.7 ± 2.3	21.4 ± 4.4	23.5 ± 3.4
Post	Con	0.7 ± 1.3	1.1 ± 1.7	1.3 ± 1.9	3.4 ± 2.4	3.2 ± 1.6	10.8 ± 1.8	19.4 ± 5.1	24.0 ± 2.1
	ST	0.9 ± 2.5	2.7 ± 3.0	1.0 ± 2.8	3.4 ± 2.8	2.9 ± 1.7	8.4 ± 2.9	19.0 ± 7.0	22.8 ± 2.7
	$p =$	.92	.44	.90	.75	.38	.62	.75	.73

Note. Pre = pre-intervention visit; Post = post-intervention visit; Con = control group; ST = Self-talk group. *p* values = univariate interaction term

2.4.3. Effect of Self-talk on TTE

As predicted, motivational self-talk had a significant effect on TTE (Group x Test interaction, $F(1, 22) = 8.01$, $p = .01$). Follow up tests revealed that TTE increased significantly from pre-test (637 ± 210 seconds) to post-test (751 ± 295 seconds) in the motivational self-talk group ($p < .05$). Moreover, all but two of the participants randomized to the motivational self-talk intervention improved their TTE. In comparison, TTE in the control group did not change significantly across tests (pre-test 487 ± 157 seconds, post-test 475 ± 169 seconds). Pre-test TTE was significantly different between groups however (see Figure 2.1). Consequently, further analysis was performed using ANCOVA whereby baseline TTE was controlled as the covariate. Accordingly, the effect of motivational self-talk upon TTE remained significant, $F(1, 21) = 4.49$, $p = .046$. With regards to the practical effect of motivational self-talk, the overall difference in pre-intervention to post-intervention changes in TTE between groups was 126 seconds ($d = 1.15$, 90% CI [49, 202]) in favour of the motivational self-talk group (see Figure 2.2). This equated to a *very likely beneficial* practical effect of motivational self-talk on TTE (beneficial/trivial/harmful%; 99/1/0%).

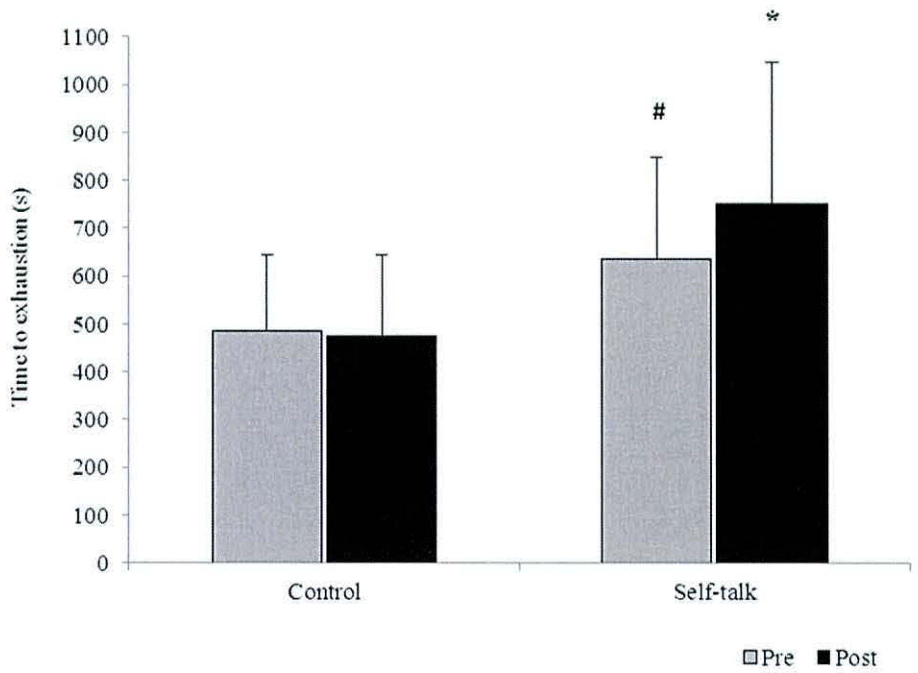

Figure 2.1. Mean (± *SD*) pre-intervention and post-intervention TTE for control group and self-talk group. # indicates significant difference between groups during corresponding visit. * indicates significant difference between pre-intervention and post-intervention.

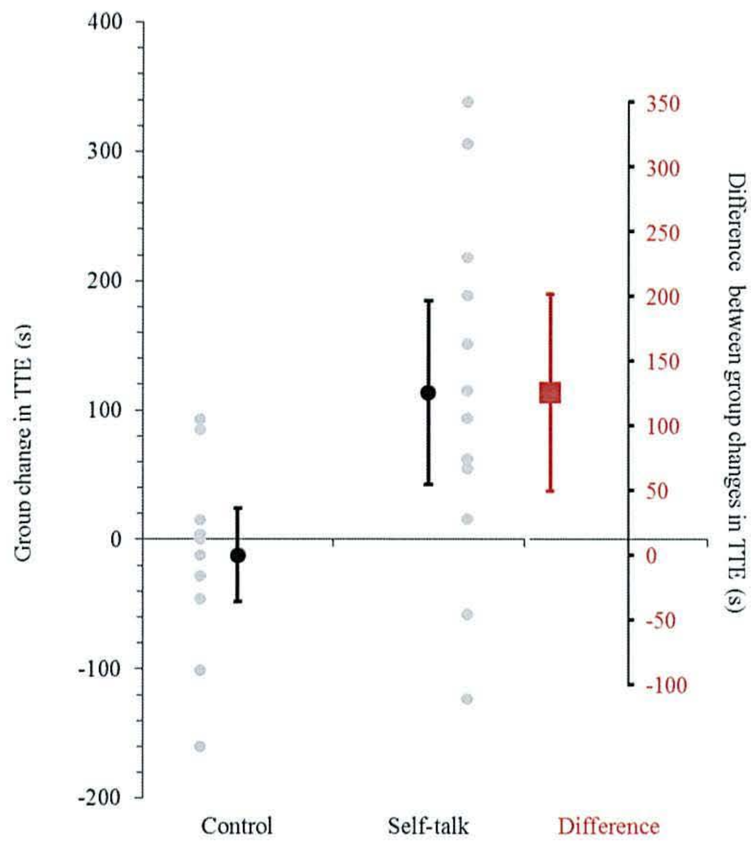

Figure 2.2. Mean (± 90% *CI*) pre-intervention to post-intervention change in TTE for control group and self-talk group (black dots) and individual pre-intervention to post-intervention changes within each group (grey dots). Floating secondary y-axis denotes overall difference between group changes (Red square).

2.4.4. Effect of Self-talk on Mean Cadence, RPE, Facial EMG Amplitude, Heart Rate, and Blood Lactate Concentration at Exhaustion

No significant Group x Test interaction or main effect of group was evident for mean cadence (see Table 2.3). A main effect was however found for visit, $F(1, 22) = 5.66$, $p = .026$. No significant Group x Test interaction or main effect of test were present for RPE at exhaustion. Importantly, RPE values at exhaustion indicated that participants in both groups disengaged from the TTE test upon reaching maximal effort during both the pre-intervention and post-intervention visits. Similarly no Group x Test interactions and main effects of test were evident for facial EMG amplitude throughout the last full minute prior to exhaustion, heart rate at exhaustion, and blood lactate concentration sampled 3 min after exhaustion.

Table 2.3. Mean ± SD of physiological and perceptual measures at exhaustion

	Control		Self-talk	
	Pre	Post	Pre	Post
Mean Cad (RPM)	77.3 ± 6.2	77 ± 9	77.5 ± 9.4	81.2 ± 9.0[a]
End RPE	9.2 ± 0.7	10.2 ± 2.0	10.1 ± 0.6	10.0 ± 0.3
End fEMG Amp (μV)	30.4 ± 25.1	30.4 ± 19	51.1 ± 61.2	45.8 ± 47.4
HR_{max} (beats · min^{-1})	187.0 ± 10.0	187.3 ± 10.7	182.4 ± 10.3	187.4 ± 11.5
End Lac (mmol · l)	9.7 ± 2.8	9.0 ± 1.8	8.5 ± 2.3	8.9 ± 2.5

Note. Mean Cad = mean cadence; End Lac = end exercise lactate; HRmax= end exercise heart rate; End fEMG Amp = end exercise facial EMG amplitude; End RPE = end exercise percpetion of effort; Pre = pre-intervention visit; Post = post-intervention visit

[a] = significantly greater than pre-intervention visit

2.4.5. Effects of Self-talk on Heart Rate, Facial EMG Amplitude, and RPE at Iso-time During the TTE Test

Mean calculated iso-times were greater for the self-talk group at both 50% and 100% with mean 50% iso-time occurring at 315 ± 109 s for the self-talk group in comparison to 230 ± 80 s for the control group and mean 100% iso-time occurring at 624 ± 228 s for the self-talk group and 430 ± 163 s for the control group. Iso-time data for heart rate and facial EMG amplitude are reported in Table 2.4. Motivational self-talk did not affect heart rate and facial EMG amplitude, with no significant Group x Test x Iso-time interactions present for these variables. However, as expected, both heart rate (main effect of iso-time, $F(1.41, 29.57) = 203.62$, $p = .001$) and facial EMG amplitude (main effect of iso-time, $F(2, 44) = 10.43$, $p = .01$) increased significantly over iso-time regardless of treatment or visit.

As hypothesized, motivational self-talk had a significant effect on RPE at iso-time (Group x Test x Iso-time interaction, $F(2, 49) = 3.85$, $p = .029$; see Figure 2.3). Follow up tests revealed no significant effect of motivational self-talk on RPE at 0% iso-time, demonstrating that RPE was equal between groups at the onset of the TTE test (control: pre-test 4.3 ± 1.6, post-test 3.8 ± 1.6; self-talk: pre-test 4.0 ± 1.0, post-test 3.5 ± 0.7). The effects of motivational self-talk upon RPE were however demonstrated by a significant Group x Test interaction at 50% iso-time, $F(1, 22) = 6.7$, $p = .017$, with a significant reduction in RPE at post-test (6.4 ± 0.8) compared to pre-test (7.3 ± 0.6) in the self-talk group ($p < 0.05$) and no statistical difference between pre-test (6.9 ± 1.9) and post-test (7.0 ± 1.7) in the control group. A comparable, but non-significant, trend was present for motivational self-talk at 100% iso-time (Group x Test, $F(1, 22) = 2.99$, $p = .01$). RPE was lower at post-test (9.0 ± 0.8) compared to pre-test (9.8 ± 0.5) in the self-talk group despite a similar RPE in the control group (pre-test 9.1 ± 1.7, post-test 9.3 ± 2.4). These values equated to negligible difference in pre-test to post-test changes in RPE between groups at 0% iso-time ($d = 0.05$ [-0.51, 0.60]), hence the practical effect of self-talk at 0% iso-time was *unclear* (35/38/27%). At 50% iso-time this difference in pre-test to post-test changes in RPE between groups corresponded to 0.95 units on the Borg CR10 scale. This favored a lower RPE following motivational self-talk ($d = 1.05$ [-1.56, -0.31]). Practically this effect was *very likely beneficial* (98/2/0%). At 100% iso-time again the overall difference in RPE was 0.95 lower following motivational self-talk ($d = 0.68$ [-1.93, 0.03]). This effect was *likely beneficial* (87/11/2%).

Table 2.4. Mean ± SD control group and self-talk group values for, heart rate and facial EMG amplitude at 0%, 50% and 100% iso-time during the TTE tests.

		Control			Self-talk		
		0%	50%	100%	0%	50%	100%
HR (beats · min^{-1})[a]	Pre	159 ± 12	178 ± 10	186 ± 9	152 ± 11	174 ± 8	182 ± 10
	Post	159 ± 10	179 ± 12	187 ± 12	158 ± 13	177 ± 10	186 ± 11
fEMG Amp (μV)[a]	Pre	12.7 ± 9.7	16.0 ± 13.2	28.5 ± 24.8	10.7 ± 4.4	13.0 ± 5.7	50.4 ± 63.4
	Post	12.7 ± 6.6	19.2 ± 15.3	25.2 ± 17.6	11.0 ± 3.6	15.9 ± 10.9	37.5 ± 34.4

Note. HR = heart rate; fEMG Amp = facial EMG amplitude; Pre = pre-intervention visit; Post = post-intervention visit

[a] = significant increase over iso-time

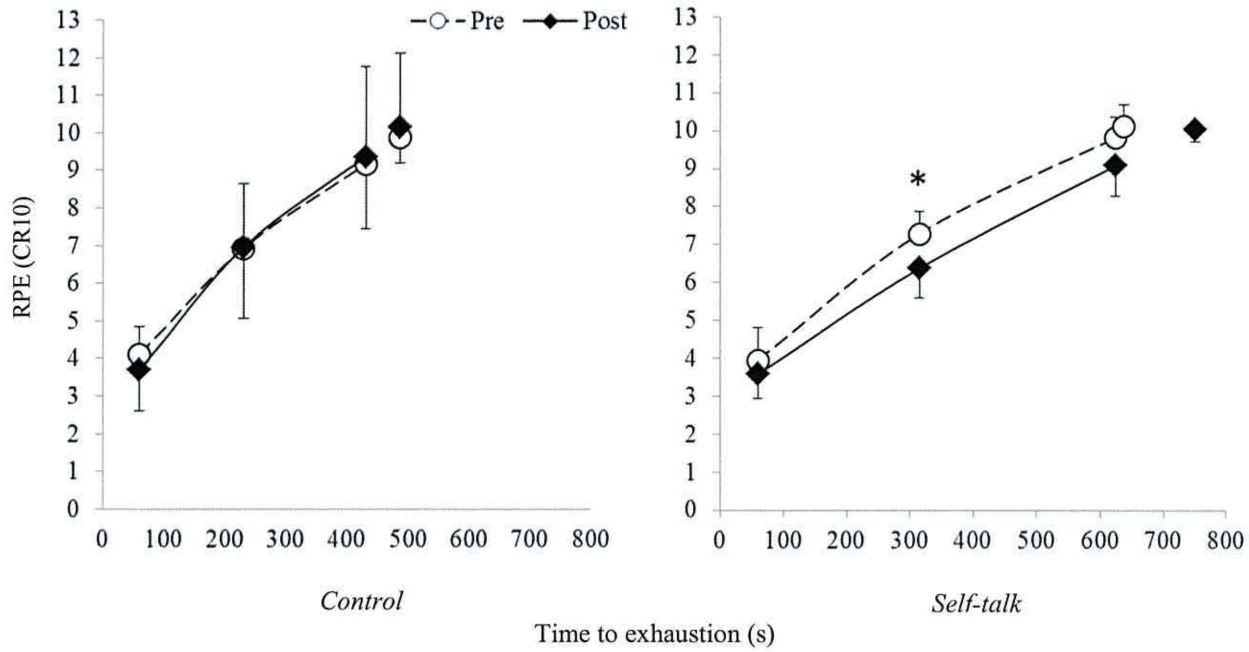

Figure 2.3. Mean (± *SD*) RPE at iso-times of 0%, 50%, and 100% for the control group and self-talk group. Unconnected markers represent RPE at exhaustion. *indicates significant difference between pre-intervention and post-intervention at a specified iso-time.

2.5. Discussion

This study investigated the effects of motivational self-talk upon RPE and physical endurance within the framework of the psychobiological model of endurance performance (Marcora et al., 2008; Marcora et al., 2009; Marcora & Staiano, 2010). As hypothesized, motivational self-talk reduced RPE and increased TTE during high-intensity cycling exercise. Specifically, motivational self-talk reduced RPE at 50% iso-time during the TTE test with a similar, but non-significant trend at 100% iso-time. In addition, this use of motivational self-talk equated to a *very likely* practically beneficial effect on endurance, as well as *very likely* and *likely* practically beneficial effects on RPE at 50% and 100% iso-time respectively. The present study is therefore unique as it is the first to experimentally demonstrate that motivational self-talk reduces RPE, and provides empirical support for previous suggestions that self-talk enhances physical endurance (Hamilton et al., 2007; Schuler & Langens, 2007). This is an important finding given the absence of experimental support for the asserted effects of motivational self-talk upon effort (Hardy et al., 2001) and task termination (Gammage et al., 2001).

The present findings are supported by the established effects of other endurance based psychological interventions. For instance, although using a different type of test, a psychological skills package containing self-talk has previously been found to enhance running distance in the heat by 8% (Barwood et al., 2008). The 18% improvement in TTE in the present study depicts the utility of motivational self-talk as a potential performance enhancing strategy during endurance exercise. This is contextualized by its comparability to the potent performance enhancing impact of psycho-stimulant drugs (28%; Jacobs & Bell, 2004). The utility of this psychological strategy is further bolstered by the fact that the 18% improvement In TTE was deemed to be *very likely* practically beneficial. Crucially, that this significant and practically beneficial improvement was associated with a reduction in RPE exemplifies the degree to which psychological factors may independently affect physical endurance. Collectively, this supports the perspective that RPE is an important determinant of physical endurance (Marcora et al., 2008; Marcora et al., 2009; Marcora & Staiano, 2010).

Attentional and informational processing frameworks have previously been suggested to account for the performance-enhancing effects of self-talk (Hardy, 2006). However, the fact that motivational self-talk instigated a reduction in RPE during the TTE test provides a novel theoretical framework to explain how this strategy can enhance endurance: the psychobiological model proposed by Marcora and colleagues (Marcora et al., 2008; Marcora et al., 2009; Marcora & Staiano, 2010). The psychobiological model of endurance performance, based on motivational intensity theory (Brehm & Self, 1989), suggests that an individual will terminate endurance exercise either when the effort required by the task exceeds his/her potential motivation, or when a true maximal effort is considered to have occurred and continuation of the task is perceived as impossible (Marcora et al., 2008; Marcora et al., 2009; Marcora & Staiano, 2010). In the present study a drop of almost one point in RPE was observed at 50% and 100% iso-time when using motivational self-talk during the TTE test. This perceptual effect of motivational self-talk delayed the point at which participants perceived very high effort and correspondingly decided to terminate the TTE test. Importantly however, RPE at task termination was near maximum for all subjects, and was not statistically different between groups. This confirms that all participants invested maximum effort in the tests despite the difference in TTE. Popular strategies such as aerobic training (Ekblom & Golobarg, 1971), nutritional intervention (Blackhouse et al., 2005), inspiratory muscle training (Gething, Williams, & Davies, 2004) and psycho-stimulant administration (Jacobs & Bell, 2004) have already demonstrated that a reduction in RPE enhances physical endurance. That a psychological strategy such as motivational self-talk is able to achieve similar benefits supports the contention that any physiological or psychological factor affecting RPE and/or potential motivation will affect endurance performance (Marcora et al., 2008; Marcora et al., 2009; Marcora & Staiano, 2010). As RPE is sensitive to both psychological and physiological factors, the framework offered by the psychobiological model potentially provides a unifying explanation for the positive effects of both psychological and physiological strategies on endurance performance. Accordingly, strategies designed to target beneficial changes in RPE through this psychobiological framework may pose a new paradigm for endurance performance enhancement.

The present study was not designed to identify how motivational self-talk might cause a reduction in RPE. However, a number of reasons may be forwarded. For instance, despite inconclusive findings RPE has been linked to the use of associative and dissociative strategies (e.g., Lind, Welch, & Ekkekakis, 2009). Accordingly it is possible that the use of motivational self-talk served as a means of dissociation from the effort based requirements of the task, hence altering the momentary RPE. Furthermore, it is also plausible that the use of motivational self-talk during the TTE test increased the perceived ability of the participants to maintain the required power output for longer. Correspondingly it is this cognitive effect of motivational self-talk that may have reduced RPE and delayed the point at which a maximal effort was believed to have occurred. In support of this hypothetical cognitive mechanism, the performance benefits that are derived from motivational self-talk have previously been associated with enhanced self-efficacy (Hardy et al., 2001; Hatzigeorgiadis, Zourbanos, Goltsios, & Theodorakis, 2009). Although using a different mode and intensity of exercise to that of the present study, self-efficacy has also been reported to predict 14% of the variance in RPE during 30 minutes of moderate intensity running (Rudolph & McAuley, 1996). Additionally, psychophysiological investigations of motivational intensity theory have demonstrated that perceived ability can modify effortful behavior. For example, participants with high perceived ability are more willing to exert effort at greater task difficulties whereas individuals with low perceived ability withhold effort and disengage from a task more readily as difficulty increases (Wright & Dill, 1993; Wright & Dismukes, 1995). Moreover, individuals with low perceived ability appear to experience greater effort than those with high perceived ability at an absolute level of task difficulty when task difficulty is relatively low (Wright & Dill, 1993). From this perspective, participants in the control group would not be expected to alter their perceived ability thus RPE and TTE would remain similar, as was the case. By extension, it is noteworthy that no statistical difference in RPE was evident between groups at 0% iso-time. Furthermore, mood and motivation were also not statistically different between groups before the TTE test. This suggests that it was the effect of motivational self-talk during the task rather than an enhanced sense of perceived ability, mood or motivation upon entering the test that led to the 18% improvement in TTE.

Heart rate and facial EMG amplitude were also recorded during the TTE test, along with blood lactate concentration 3 minutes after task termination. Heart rate and blood lactate at exhaustion were not significantly different between groups. Similarly, motivational self-talk did not have a significant effect on heart rate at iso-time. While it would be inappropriate to declare that all unmeasured physiological parameters were also similar between groups, these data limit the possibility that the increase in TTE that occurred in the self-talk group can be explained by traditional musculo-energetic and cardio-vascular mechanisms (Allen et al., 2008). In addition, models of pacing such as the afferent feedback model (Amann et al., 2011) have been recently proposed to regulate endurance performance. This model is specifically founded on the premise that the brain limits performance according to the physiological condition of the body. However, a purely psychological strategy such as self-talk is unlikely to modify afferent feedback from the locomotor muscles (Amann et al., 2011), or alter any threat to physiological homeostasis (Noakes, 2012). Therefore these models are also unable to fully account for why the present psychological intervention was able to reduce RPE and enhance TTE.

Previously, facial EMG amplitude has been shown to correlate with RPE during weightlifting (de Morree & Marcora, 2010), and to differentiate between two different exercise intensities during cycling to exhaustion (de Morree & Marcora, 2012). In the current study, like RPE, facial EMG amplitude increased significantly in both groups during the TTE test. Facial EMG amplitude at iso-time was not significantly affected by motivational self-talk however, despite its significant effect on RPE. A possible explanation for this discrepancy is that the increase in facial EMG amplitude that occurs during high-intensity cycling exercise reflects motor irradiation (de Morree & Marcora, 2012). Under these circumstances the spreading of activation in cortical and subcortical regions stimulates not only the muscles involved in the task but also task-irrelevant muscles (Hoy, Fitzgerald, Bradshaw, Armates, & Georgiou-Karisianis, 2004), such as the facial muscles (de Morree & Marcora, 2010). Alterations in facial EMG activity may therefore not be expected to occur when differences in RPE result from cognitive factors such as motivational self-talk. This is supported by the fact that cognitive effort and facial EMG amplitude are not consistently associated in the psychophysiology literature (Capa, Audiffren, & Ragot, 2008, Silvestrini & Gendolla, 2009), and explains why facial EMG differences were not discernible between groups despite the clear change in RPE in the self-talk group.

In order to contextualize the present findings, potentially limiting aspects of the study should also be acknowledged. For example, a TTE test is suggested to be less ecologically valid than, for example, a time-trial, because it excludes pacing. However, given that the present study aimed to establish the effects of motivational self-talk upon RPE and task termination, as opposed to pacing, the influence of a self-paced power output such as that during a time-trial would have made it difficult to precisely establish the effect of the intervention on our dependent measures. The constant power output during a TTE test therefore permitted a more stable milieu from which preliminary conclusions about the experimental measures could be made. Moreover, some authors think that the large variability in TTE tests can make it difficult to detect real changes in performance (Jeukendrup & Currell, 2005). However, it has been demonstrated that TTE tests and time-trial tests have similar sensitivity to changes in endurance (Amann et al., 2007). This is because despite the larger variability in TTE tests, performance enhancement also tends to be much greater (Hopkins, Schabort, & Hawley, 2001), thus compensating for this larger variability. Put another way, the signal to noise ratio remains similar to that of a time-trial. The present study also did not include a familiarization visit. It is acknowledged that this could have led to practice effects across Visits 2 and 3. Nonetheless, the lack of an increase in performance in the control group during Visit 3 somewhat argues against this.

During the manipulation check ten of the twelve participants in the control group reported employing some self-talk during their TTE test. This however corresponds to previous findings (Gammage et al., 2001) whereby 95% of a sample of 164 exercisers reported the use of self-talk during their workout. In this regard, given the prevalent nature of self-talk, an inherent issue with control groups is whether it is realistic to eliminate self-talk entirely. Moreover, alternative approaches for the control group are not without their own issues; for example, the introduction of potential confounds during distracter type tasks. Nevertheless, as performance was only enhanced in the self-talk group this signifies that it may be practiced and specifically structured motivational self-talk (Hardy et al., 2001) that provides the key to enhancing endurance as opposed to the use of self-talk per se. Practically, this suggests that individuals who take part in endurance exercise should be trained in the use of structured and personalized motivational self-talk.

Due to the problematic nature of control groups in self-talk research, the possibility that the present findings could be attributed to a placebo effect cannot be entirely eliminated. However, a placebo driven 18% improvement in TTE might be regarded as substantial. This is supported by a notably lesser change in performance of approximately 6.5% in the placebo group of a placebo controlled study utilizing a comparable mode, exercise intensity, and sample population as the current one (Gething et al., 2004). Similarly, it is possible that the additional thirty minutes that the self-talk group spent with the experimenter during Stage 1 of the self-talk workbook procedure could have provoked either experimenter effects or experimenter bias. Once more however, an 18% improvement in response to either of these would appear extremely large.

In light of the present findings, it is important that future research examines the effects of motivational self-talk upon RPE during time-trial performance so as these findings can be extended more specifically to competition. In addition, to make these findings more relevant to individuals of a superior training standard than the participants in the current study, similar investigations should be performed on elite and sub-elite athletic cohorts if possible. Moreover, owing to the proposed link with perceived ability, the interplay between motivational self-talk, RPE, and perceived ability should be experimentally clarified. Likewise, it would be interesting to determine whether the novel theoretical framework provided by the psychobiological model of endurance performance extends to other psychological strategies such as imagery and goal setting. Finally, in recognition of the psychobiological link between motivational self-talk and physical endurance, it is important that the neural structures that are activated by motivational self-talk are identified. This would provide a greater understanding of the psychobiological connections between motivational self-talk, RPE and physical endurance and may offer an insight into the most effective ways to structure and verbalize self-talk in order to tailor it to specific competitive scenarios.

In summary, the present findings are the first to experimentally demonstrate that the isolated use of motivational self-talk is an effective strategy for enhancing physical endurance. Additionally, this is the first study to reveal that this enhancement is associated with a significant reduction in RPE. The latter finding has several implications. First, this supports the psychobiological model of endurance performance which proposes that the point recognized as exhaustion is determined by the conscious decision to terminate endurance exercise. Second, this supports the perspective that any intervention that affects RPE will affect endurance performance. Finally, this illustrates that psychobiological interventions designed to specifically target favorable changes in RPE may be of benefit to endurance performance and should be more extensively investigated in the context of competitive preparation for endurance athletes.

CHAPTER 3

Brain Endurance Training: Investigating a New Approach to Endurance Performance Enhancement[1]

[1]A section of this research was presented at the XXXII World Congress of Sports Medicine; Rome, September 2012

3.1. Abstract

Purpose: Demanding cognitive activity negatively effects perception of effort (RPE) and physical endurance. This suggests the existence of a neural structure that links cognitive and physical effort. Although both cognitive and physical training are known to benefit cognitive performance, the effect of cognitive training on physical performance is unknown. Accordingly, this was investigated by targeting one of the neural structures that is associated with effort in an attempt to reduce RPE and enhance physical endurance. **Method**: In a randomized between groups pre-test – post-test design, 17 participants (mean ± SD, age 42.7 ± 11.7 years; peak power output 307 ± 62 W; $\dot{V}O_{2max}$ 52.7. ± 6.8 ml·kg^{-1}·min^{-1}) cycled to exhaustion (TTE) at 80% peak power output (PPO) and 65% PPO, before and after random allocation to a 6 week brain endurance training protocol (BET) or a 6 week placebo control. **Results**: Group (BET vs. Placebo) x Test (Pre-test vs. Post-test) mixed model ANOVA's revealed no significant interaction for performance at 80% PPO (p = .86) or 65% PPO (p = .11). A *likely beneficial* practical effect of BET on TTE was evident at 65% PPO (beneficial/trivial/harmful%; 83/15/2%) as signified by an increase in TTE that was 229 seconds beyond that of the placebo group (d = 0.47, 90% CI [-10, 467]). Although, mixed model ANOVA's did not reveal any Group x Test x Iso-time interactions for RPE at 80% PPO and 65% PPO, a *likely beneficial* practical reduction was evident at 50% iso-time (95/4/1) during the 65% PPO following BET. **Conclusion**: This initial implementation of BET demonstrates a potentially innovative method of targeting endurance performance enhancement. Further research into this novel training strategy should therefore be developed in order to optimize the delivery of BET.

Descriptors: Cognitive Training; RPE, Psychobiological Model; Endurance Performance

3.2. Introduction

It is well known that physical endurance training elicits beneficial physical adaptations and enhances endurance performance (Joyner & Coyle, 2008; Midgley, McNaughton, & Wilkinson, 2006). Similarly, cognitive training is thought to elicit beneficial cognitive adaptations and enhance cognitive performance (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Willis et al., 2006). Research also demonstrates that acute endurance exercise can cause temporary alterations in cognitive function (Hillman, Snook, & Jerome, 2003). Furthermore, repeated bouts of physical endurance training can stimulate prolonged enhancements in cognitive performance (Cotman, Berchtold, & Christie, 2007). This suggests the presence of a neuro-cognitive connection between certain cognitive and physical processes (Kramer & Erickson, 2007). Despite evidence suggesting the existence of such a neuro-cognitive connection however, research investigating the opposite effect, (i.e., the effect of cognitive training on physical performance), has seemingly not been carried out.

One process that appears to exhibit a shared neuro-cognitive connection is the regulation of cognitive and physical effort. For example, prolonged and demanding cognitive activity before exercise is detrimental to subsequent perception of effort (RPE) and endurance performance (Marcora, Staiano, & Manning, 2009). Consistent with the proposal that RPE is a key determinant of physical endurance (de Morree & Marcora, 2012; Marcora & Staiano, 2010), the psychobiological model of endurance performance (Marcora, Bosio, & de Morree, 2008; Marcora et al., 2009) predicts that any physiological or psychological factor affecting RPE will affect endurance performance. Considering the neuro-cognitive link between demanding cognitive activity and RPE, and the positive neural adaptations that are caused by longitudinal cognitive training interventions (Jaeggi et al., 2008), a cognitive training intervention designed to specifically provoke positive adaptations in RPE is appealing. Approaching this by implementing a demanding cognitive training intervention to repeatedly stimulate the neural structures that are associated with cognitive and physical effort may therefore represent a novel way of reducing RPE and enhancing physical endurance.

One neural structure that regulates both cognitive effort (Boksem, Meijman, & Lorist, 2006) and physical effort (Williamson et al., 2001) is the anterior cingulate cortex (ACC). For instance, rats with ACC lesions mobilize less effort in return for a reduced quantity of food in comparison to rats with an undamaged ACC (Walton, Bannerman, Alterescu, & Rushworth, 2003), while humans who recover from an ACC infarction report a loss of will during the affliction (Mulert, Menzinger, Leicht, Pogarell, & Hegerl, 2005). In addition, ACC activation occurs in response to handgrip exercise and cognitive activity in healthy humans (Critchley et al., 2003) and during imagined handgrip exercise under hypnosis (Williamson et al., 2002), whereas ACC activation is attenuated during dynamic cycling exercise following hypnotically induced decreases in effort perception (Williamson et al., 2001).

Alterations in mid-brain dopamine are also thought to mediate cognitive (Lorist & Tops, 2003) and physical effort (Salamone et al., 2007). Specifically, Denk et al. (2005) found that rats injected with a dopamine receptor antagonist opt for low rewards that require less physical effort more frequently than placebo injected rats. Conversely, humans were more willing to invest physical effort in pursuit of reward after extracellular dopamine was raised through amphetamine intake (Wardle, Treadway, Mayo, Zald, & de Wit, 2011). Similar findings have led Salamone, Correa, Mingote, and Weber (2003) to suggest that dopaminergic alterations in the ACC – nucleus accumbens circuitry diminish the mobilization of effort during physical activity. Moreover, Lorist, Boksem, and Ridderinkhof (2005) have cited that reduced dopaminergic activation of the ACC is a key cause of cognitive fatigue.

The ACC also regulates executive processes such as conflict resolution and error detection. As such it is activated by cognitive tasks that utilize these processes. Cognitive tasks that have been found to activate the ACC include the Eriksen flanker task (Lorist et al., 2005), the go/no-go task (Hester, Fasenbender, Garavan, 2004; Kato, Endo, & Kizuka, 2009) the AX-CPT (Chiew & Braver, 2011), and the Stroop colour word task (Hanslmayr et al., 2008; Swick & Jovanovic, 2002). Importantly, prolonged activation of the ACC using these tasks can cause cognitive fatigue (Lorist et al., 2005; Boksem et al., 2006) within one hour (Kato et al., 2009). Moreover, processes such as action monitoring (Boksem et al., 2006) and error detection (Lorist et al., 2005) are compromised after twenty minutes (Kato et al., 2009).

Crucially, the repeated use of similar tasks during cognitive training programmes has been shown to increase neural activity (Olesen, Westerberg, & Klingberg, 2004), improve cognitive performance (Jaeggi et al., 2008; Klingberg, Forssberg, & Westerberg, 2002) and stimulate neuro-physiological adaptations (Ceccarelli et al., 2009; Draganski et al., 2006). Recently, McNab et al. (2009) demonstrated that five weeks of cognitive training was able to enhance working memory and alter dopamine receptor binding. Similarly Bäckman et al. (2011) reported enhanced dopamine release and improved letter memory performance following a five week cognitive programme of updating training. This supports the notion that the neuro-cognitive resources that regulate cognitive and physical effort undergo positive adaptations when they are repeatedly targeted. Accordingly, targeting these specific neuro-cognitive resources with a demanding and effortful cognitive training programme may stimulate positive neural alterations that transfer into a reduced RPE during physical endurance tasks.

This study aimed to reduce RPE and enhance physical endurance using a novel cognitive training programme; brain endurance training (BET). Accordingly, BET was comprised of a six week protocol of prolonged and demanding cognitive tasks that are known to target the ACC. In order to investigate the effect of BET on the neuro-cognitive mechanisms that are involved in effortful behaviour, an indirect estimate of dopamine activity was obtained by measuring spontaneous eye blink rate (Karson, 1983) and an indirect measure of cognitive effort was established using heart rate variability (HRV). Spontaneous eye blink rate has been used to objectively indicate dopamine activity during cognitive control (Dreisback et al., 2005), stimulant drug use (Colzato, van den Wildenberg, & Hommel, 2008) and response inhibition (Colzato et al., 2009). Furthermore HRV has been suggested to reflect ACC activity during effortful cognitive tasks (Critchley et al., 2003) with HRV in the mid-frequency domain (0.07 – 0.14 Hz) providing an objective measure of cognitive effort (Capa et al, 2011). It was hypothesised that six weeks of BET would significantly enhance cycling time to exhaustion (TTE) at both 80% PPO and 65% PPO, and that RPE would be reduced during each TTE test.

3.3. Method

3.3.1. Participant Characteristics and Ethics

Twenty eight individuals volunteered for the study (see Figure 3.1). Seventeen individuals completed the study (12 male & 5 female; mean ± *SD*, age 42.7 ± 11.7 years, height 175 ± 7 cm, weight 72.8 ± 10.3 kg, PPO 306 ± 62 W, maximum oxygen uptake ($\dot{V}O_{2max}$) 52.7. ± 6.8 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$). Ethical approval for the study was granted by the ethics committee of the School of Sport, Health and Exercise Sciences (SSHES), Bangor University. Accordingly, prior to taking part each participant completed an informed consent form along with a standard medical questionnaire to confirm their present state of health. This confirmed that all participants were healthy and free from injury. They were also actively engaged in endurance training (running, cycling, or triathlon) on a minimum of two occasions per week, with a mean weekly training load of 6.10 ± 1.75 hours. Before taking part, participants received a detailed overview of all study procedures and requirements, but remained naive to the aims throughout. Upon cessation of the study, participants were debriefed about its purpose and requested not to discuss this with others. Participants received a payment of £20 for taking part in the study. Once the study was complete, prizes of £250, £125, and £75 were also respectively awarded for first, second, and third best overall time at each TTE intensity.

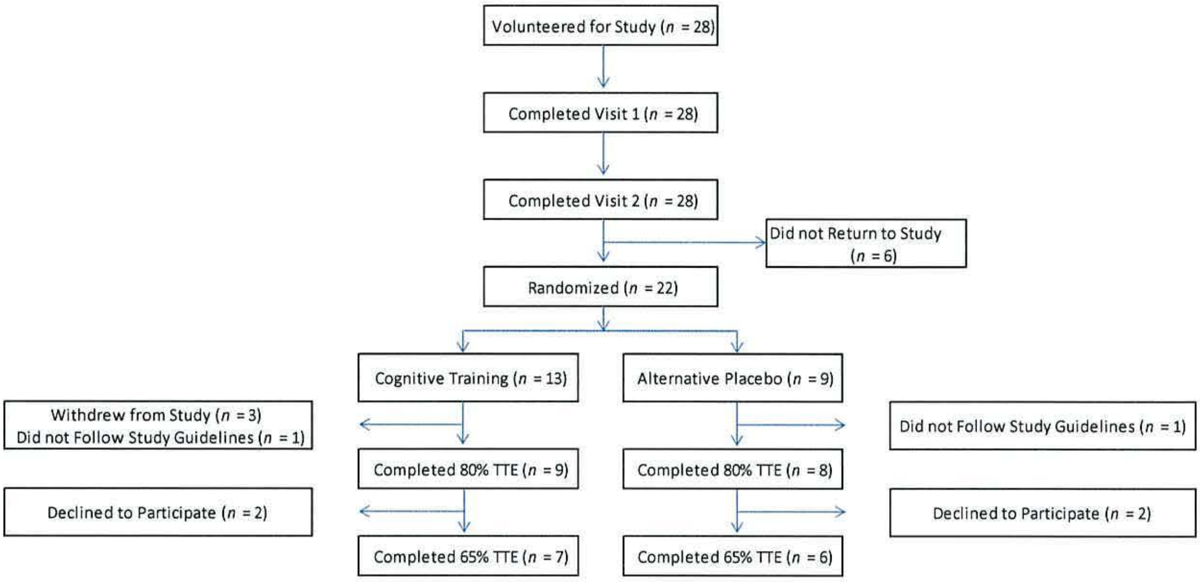

Figure 3.1. Flow diagram detailing stages of participant withdrawal during the intervention

3.3.2. Study Design and Procedures

The study consisted of a randomized, placebo controlled, between groups, pre-test post-test design in which all participants visited the laboratory on four separate occasions. All trials were conducted at the same location on the same electromagnetically braked cycle ergometer (Excalibur Sport, Lode, Groningen, the Netherlands), with saddle and handlebar specifications adjusted to suit the preference of each subject and maintained for each visit.

During Visit 1 participants first completed the informed consent questionnaire and an instruction checklist. After this, anthropometric measurements were recorded. An incremental ramp test was then carried out on a cycle ergomenter to establish peak power output (PPO) and $\dot{V}O_{2max}$. The ramp test began with a two minute rest after which power output was increased by 25W every minute until volitional exhaustion. Exhaustion was defined as voluntary task cessation by the participant, or the inability to maintain a pedal frequency of 60 revolutions per minute (RPM) for 5 seconds despite verbal encouragement. For the task, the ergometer was set in hyperbolic mode; this allows power output to be altered independently of pedal frequency over a range of 30-120 RPM. The participant was also instructed to always remain in the saddle at all times. $\dot{V}O_{2max}$ was measured breath by breath via a computerized metabolic gas analysis system (Metalyzer 3B, Cortex Biophysik, Leipzig, Germany) connected to an oro-(mouth) mask (7600 series, Hans Rudolph, Kansas City, MO). The device was calibrated before each test using a known concentration of gases and a 3.0 litre calibration syringe (Series 5530, Hans Rudolph). Heart rate was recorded 15 seconds from the end of the two minute rest via wireless chest strap radio telemetry (S810i, Polar Electro, Kempele, Finland). It was then measured every minute thereafter along with RPE which was obtained using the Borg CR10 scale (W. G. Borg, 1998).

Visit 2 was a familiarisation session in which participants carried out all questionnaire measures, cognitive tasks and physical tasks that were to be used during Visits 3 and 4. Visit 3 represented the pre-intervention visit. Upon arrival for this visit all participants completed mood and motivation questionnaires (see Psychological questionnaires). Following this, participants remained seated for ten minutes in a quiet room while recordings of resting R-R interval data were obtained (see Measurement of heart rate variability). The final five minutes of these recordings were used as a measurement of resting HRV. The first segment of the pre-intervention trial commenced with a five minute baseline measurement of spontaneous eye blink rate (see Measurement of spontaneous eye blink rate). Subsequently, participants carried out a 15 minute computer based cognitive task (see Cognitive task) after which a second five minute measurement of eye blink rate was acquired. Following these procedures, the first TTE test took place. For the TTE test, participants were positioned on the cycle ergometer (set to hyperbolic mode) and instructed to remain in the saddle at all times. The test began with a three minute warm up at 40% of the participants PPO. After three minutes the power output was automatically increased to a power output corresponding to 80% PPO. Pedal cadence was freely chosen between 60 – 100 RPM and was recorded every minute during the test. RPE (see Measurement of effort) was recorded using the 11 point Borg CR10 at one minute intervals during the test, as was heart rate. TTE was defined as the cycling time accrued from the onset of the 80% PPO TTE test until the point at which either the participant voluntarily terminated the test or pedal cadence had fallen below 60 RPM for five consecutive seconds. Standardized verbal encouragement was provided by the same experimenter during all TTE tests. To avoid bias, the experimenter stood behind participants at all times, however a fan was placed approximately 60 cm in front of the cycle ergometer. Participants were provided with the option of completing the TTE test with or without the use of the fan and completed the test during the post-intervention visit under identical conditions. Three minutes after the cessation of the TTE test, participants provided an earlobe sample of 5μl of whole fresh blood for lactate analysis ($mmol \cdot l^{-1}$). Blood was collected for lactate sampling using a calibrated portable lactate analyzer (Lactate Pro LT-1710, Arkray, Shiga, Japan). After lactate sampling participants performed the third eye blink rate measurement which was followed once more by the same 15 minute cognitive task as earlier. A seated 30 minute rest period in a quiet room then ensued. This ensured a 90 minute gap between TTE tests to allow participants to return to a rested state prior to the second test (Burnley, Doust, & Jones, 2006). After the rest period, participants began the second segment of the pre-intervention trial which replicated the first segment other than intensity of the second TTE test and the omission of an eye blink measurement immediately following the rest. The second TTE test was preceded with an earlobe sample of 5μl of whole fresh blood for lactate analysis ($mmol \cdot l^{-1}$). This was to verify that the physical inactivity punctuating the TTE tests had allowed participants to return to a rested state (Burnley et al, 2006). As with the first TTE test, participants were positioned on the cycle ergometer (set to hyperbolic mode) and instructed to remain in the saddle at all times. The test then commenced with a three minute warm up at 30% PPO. After three minutes the power output was automatically increased to a power output corresponding to 65% PPO. All procedures for this TTE test reflected those of the preceding TTE test at 80% PPO other than the fact that during this test RPE was recorded at three minute intervals. At the end of Visit 3, participants were randomly allocated to either six weeks of BET (See BET intervention) or a six week placebo control group (see Placebo control supplementation). Group allocation remained double blind until randomization. Visit 4 was the post-intervention visit. This visit took place after participants had completed their 6 week intervention. All procedures carried out during Visit 4 were identical to those of Visit 3.

Visits 1, 2 and 3 were separated by a minimum of 72 hours each, while Visits 3 and 4 were separated by a minimum of 42 days, during which the BET intervention or the placebo control treatment took place. All participants returned for Visit 4 no more than 10 days after their allocated treatment had ended. The BET intervention or placebo supplementation always commenced on the first Monday that followed Visit 3. During this time participants recorded their physical training load using session RPE (see Monitoring of physical training load). Participants attended the laboratory at the same time of day for each of their visits. As instructed, prior to each visit, participants consumed an amount of water equivalent to least 35 $ml \cdot kg^{-1}$ body weight during the preceding 24 hours and attained at least 7 hours of sleep the night before. Participants also avoided heavy exercise in the 24 hours before testing and refrained from caffeine consumption and nicotine in the 12 hours leading up to each test.

3.3.3. BET Intervention

The BET intervention was comprised of 30 cognitive training sessions. This consisted of five cognitive training sessions per week for six consecutive weeks. Only one cognitive training session per day was permitted during this time. Sessions were performed remotely via a dedicated website (Quizengine.co.uk) and participants were free to choose which cognitive task they performed and the time of day that they performed it. Participation was logged automatically by the website after each session. Cognitive training duration was progressively increased throughout the intervention. As such all tasks during Weeks 1 and 2 lasted for 30 minutes, all tasks during Weeks 3 and 4 lasted for 45 minutes, and all tasks during Weeks 5 and 6 lasted for 60 minutes. This approach accounted for the possibility of neural adaptation to the cognitive training, thus ensuring that cognitive demand was maintained throughout the intervention. Three cognitive tasks were selected for the BET intervention based on their ability to target the ACC and elicit cognitive fatigue. The three tasks were the AX-CPT (Marcora et al., 2009), the Eriksen Flanker Task (Lorist et al., 2005), and the Go / nogo task (Kato et al., 2009). These selected tasks were implemented as follows.

3.3.3.1. AX-CPT

A continuous string of letters was visually presented one after the other in an unbroken sequence on a computer screen. Every string of four letters constituted one trial. Each four letter trial consisted of a cue-probe sequence in which the first letter represented the cue and the fourth letter represented the probe. A target trial was defined as a cue-probe sequence in which the letter A appeared as the cue and the letter X appeared as the probe. A non-target trial was defined as a cue-probe sequence in which one or both of these letters was replaced by any of the remaining letters of the alphabet. Participants were instructed to respond with a left back slash key-press following all target trials and a right forward slash key-press following all non-target trials. Participants were also instructed to respond as quickly and as accurately as possible during each trial. The trials were presented in pseudorandom order with target trials (AX) occurring with 70% frequency and non-target trials occurring with 30% frequency. Non-target trials were further divided equally (10%) into BX, AY, and BY trials. A BX trial occurred when a valid cue (letter A) was replaced by any other letter of the alphabet. An AY trial occurred when a valid probe (letter X) was replaced by any other letter of the alphabet. A BY trial occurred when both a valid cue and a valid probe were replaced by any other letter of the alphabet. On all trials the cue and the probe were punctuated by two distractor letters which were also represented by any letters of the alphabet other than A and X. The letters K and Y were also excluded from all trials due to their similarity to the letter X. No letter appeared more than once in each four letter trial. During all trials the cue letter was presented in red font and the probe letter was presented in blue font. All distractor letters were presented in white font. All letters were presented centrally for a duration of 300 ms in 30-point uppercase Ariel black font on a black background which was portrayed as a scoreboard on an animated graphical image. The presentation of each letter was followed by a 1200 ms interval giving a duration of 4500 ms between the presentation of the cue and the probe. All incorrect or missed responses elicited a low sounding beep and a red flash on screen as a prompt to increase speed and accuracy.

3.3.3.2. Eriksen flanker task

A horizontal five arrow array was presented collectively on a computer screen with the central arrow representing the target arrow and the remaining arrows representing the flanker arrows. Each five arrow array represented one trial. Participants were instructed to focus on the target arrow and respond with a left back slash key-press if the target arrow pointed to the left or a right forward slash key-press if the target arrow pointed to the right. Participants were also instructed to respond as quickly and as accurately as possible to each trial. All 5 arrow arrays were presented in pseudorandom order with the target arrow orientated in a corresponding direction to the flanker arrows on 60% of the trials and the target arrow orientated in an opposing direction to the flanker arrows on 40% of the trials. No trial was identical to the preceding trial and all flanker arrows were orientated in a matching direction on every trial. All arrows were coloured white and were presented centrally on a black background which was portrayed as a scoreboard on an animated graphical image. The flanking arrows were presented 100 ms before the target arrow on every trial and the flanker arrows and the target arrow disappeared simultaneously following a response. Where no response was made all arrows disappeared simultaneously after 1200ms. An inter-stimulus interval of 3000 ms minus response time was present for all trials. All arrows were 1 cm in width with the arrowhead 0.75 cm in height. Every arrow was spaced 0.25 cm apart and a small white fixation cross was displayed throughout each inter-stimulus interval in the centre of the black scoreboard. All incorrect or missed responses elicited a low sounding beep and a red flash on screen as a prompt to increase speed and accuracy.

3.3.3.3. Go-nogo task

During each trial participants were presented with either a white triangle which represented the go stimulus or a white circle which represented the nogo stimulus. All stimuli were presented one at a time with the presentation of one stimulus representing one trial. During each trial the stimulus was presented either to the right or left of a white fixation cross. This ensured four possible stimuli during the task, these being a go right, go left, nogo right, and a nogo left. On trials where the white triangle was presented participants were instructed to respond as quickly and accurately as possible with a back slash key-press on the left of the keyboard if the triangle appeared to the left of the fixation cross, or a forward slash key press if the triangle appeared to the right of the fixation cross. If a circle was presented participants were instructed to withhold a response regardless of which side of the fixation cross the circle appeared on. The stimulus was presented for 100 ms on each trial with an inter-stimulus interval of 2500 ms. The fixation cross remained on screen at all times. The order of stimulus presentation was pseudorandom with go stimuli presented on 80% of the trials and nogo stimuli presented on 20% of the trials. All incorrect or missed responses emitted a low sounding beep and a red flash on screen as a prompt to increase speed and accuracy. The triangle had an equilateral edge length of 2 cm and the circle was 2 cm in diameter, the crosshairs on the fixation cross were 0.5 cm. All stimuli were presented on a black background which was portrayed as a scoreboard on an animated graphical image.

3.3.4. Placebo Control Supplementation

The placebo control group underwent an alternative placebo treatment that was similar in duration to BET and implemented in order to be perceived by control participants as equally desirable and relevant as BET. This type of treatment is suggested to remove control group threats to internal validity that cannot be eliminated by randomization (W. Borg, 1984). The control group were therefore supplemented with one inert, calorie free pill every day for the six week intervention. This amounted 42 days of supplementation. Participants were free to choose what time of day they consumed the pill and were informed after Visit 3 that each pill contained 1000 mg of tyrosine, which acts as a precursor for the formation of the neurotransmitter dopamine. They were told that the purpose of this supplementation was to investigate whether the daily intake of a capsule of tyrosine was able to prolong endurance exercise performance. All supplemented pills were produced in the sports science laboratories at SSHES and contained 1000 mg of artificial sweetener (Splenda®, McNeil Nutritionals, Wokingham, UK) encased in a gelatine capsule (Myprotein.com®). Each participant was debriefed at the end of Visit 4 about the true content and purpose of the supplementation.

3.3.5. Cognitive Task

The computer based cognitive task that was performed throughout Visits 3 and 4 was carried out four occasions per visit. This task was used as a manipulation check to assess the success of BET via transfer effects on cognitive performance during a task that resembled those used during intervention and targeted the same area of the brain (Peterson et al., 2002). This manipulation check was based upon the number of correct responses, and reaction time during each cognitive task. As ACC activity has been associated with cognitive effort (Critchley et al., 2003), this cognitive task was also used as a manipulation check to obtain an objective measure cognitive effort using HRV (see Measurement of heart rate variability).

The selected cognitive task was a Stroop colour word task (Stroop, 1935). This task has been shown to activate the ACC (Swick & Jovanovic, 2002) whilst remaining sufficiently dissimilar to the tasks used in the BET intervention, therefore eliminating practise effects. The task consisted of the words of four colours (*BLUE, YELLOW, GREEN, RED*) that were randomly presented one at a time in the centre of the computer screen. Each colour was also presented in a specific ink colour (*BLUE, YELLOW, GREEN, RED*) such that on 50% of the trials the ink colour was congruent with the written colour word whilst on the remaining 50% the ink colour was incongruent with the written colour word. The presentation of congruent and incongruent trials occurred in pseudorandom order. For each trial, participants were requested to identify the ink colour of the written word as quickly and as accurately as possible by pressing the coloured key on the numerical section of a keyboard that matched the ink colour of the presented word. One colour word presentation represented one trial. One key was coloured to represent each colour on the task such that the number five, six, seven and eight keys were coloured blue, yellow, green and red respectively. The stimulus colour word was presented for 500 ms on each trial with an inter-stimulus interval of 2000 ms minus response time. All four of these cognitive tasks that were performed throughout each visit were identical and each lasted for 15 minutes, giving a total of 360 trials per task. The number of correct and incorrect trials along with reaction time on every trial was recorded for each task.

3.3.6. Measurement of Heart Rate Variability

A Polar S810i heart-rate monitor (Polar Electro OY, Kempele, Finland) was used to obtain R-R interval recordings for HRV measurement. This device has been shown to provide a valid measure of HRV when assessed alongside a criterion 12-lead ECG (Nunan et al., 2009). Prior to use, the monitor was dampened and securely fitted to the participant according to the manufacturer's instructions. A sampling frequency of 1000 Hz provided a temporal resolution of 1 ms for each R-R interval. All recordings were automatically stored via the accompanying polar software (Polar Precision Performance 4.03 software, Polar Electro OY, Kempele, Finland) after transfer to a password protected PC. The resulting R-R intervals were exported into Kubios HRV software 2.0 for windows (The Biomedical Signal Analysis Group, University of Kuopio, Finland). Fast Fourier transform was used to attain frequency measures of HRV. For every 15 minute cognitive task, HRV in the mid-frequency domain (0.07 – 0.14) was obtained offline to provide an objective measure of cognitive effort (Capa et al., 2011)

3.3.7. Measurement of Spontaneous Eye Blink Rate

Eye blink rates were measured under resting conditions via electrooculogram (Powerlab/16SP, Adi Instruments, Pty Ltd, Bella Vista, Australia). A pre-gelled Ag-AgCl electrode (Neuroline 72000-S, Ambu Inc, Ballerup, Denmark) with a recording area of Ø 11cm was placed above the left eye in the supraorbital region and below the left eye in the infraorbital region respectively. Both sites were swabbed with alcohol and dried prior to electrode placement. The voltage difference between these vertical electrode placements was used to detect one eye blink. One eye blink was defined as a 100 μV in a time interval of 500 ms (Colzato et al., 2007). For each 5 minute measurement participants sat quietly and comfortably in front of a white sheet containing a black cross in the centre that was placed at eye level approximately 1 meter away. Participants were instructed to remain still and look at the cross in a relaxed and natural manner for the duration of the 5 minute task. The cross had horizontal and vertical crosshair dimensions of 10 cm and was clearly visible to all participants when seated. Artefacts such as coughing, yawing, stretching or other gross body movements were detected and time stamped by the experimenter for omission from the final analysis. Raw eye blink data was analysed offline using dedicated software (Power Lab Chart V 4.2.3, Adi Instruments Pty Ltd, Bella Vista, Australia). Spontaneous eye blink rate was calculated by dividing the total number of blinks within the 5 minute period by five (Colzato et al., 2007).

3.3.8. Monitoring of Physical Training Load

Participants were instructed to maintain a steady physical training load during the six week intervention. This was to eliminate the impact of physical training on performance in the TTE tests. Accordingly, a training diary was supplied to monitor physical training load via the session RPE method (Foster et al., 2001). For this, participants were instructed to record the duration of each training session and a single average RPE for that session using the Borg CR10 scale 30 minutes after its cessation. This allowed the calculation of a training impulse value for each session by multiplying the average RPE of that session by its corresponding duration. Training load for each participant during the intervention period was then obtained by summating their impulse values from each session. An average of these values was also obtained for each participant to provide a comparison of average training load during the intervention period.

3.3.9. Measurement of Effort

RPE was measured using the modified Borg CR10 scale. Low (0.5 = *very, very light*) and high (10 = *maximum*) anchors were established using standard procedures (Noble & Robertson, 1996). Furthermore, participants were free to rate any number above 10 should the present state of effort have been perceived as higher than any previous maximal effort experienced. Standardized instructions regarding the CR10 scale were provided to all participants prior to each TTE test with the emphasis that each rating should be based upon the effort required to pedal during the test as opposed to any limb discomfort that may be associated with the exercise.

3.3.10. Psychological Questionnaires

The Brunel mood scale (BRUMS) was used to assess mood at the start of each visit. This measure of mood has been validated for use with adult populations (Terry, Lane, & Fogarty, 2003) and is frequently used within exercise settings (Berger & Motl, 2000). The measure is comprised of six subscales (anger, confusion, depression, fatigue, tension, & vigour) with four items per subscale. Items were answered on a 5-point Likert type scale (0 = *not at all*, 1 = *a little*, 2 = *moderately*, 3 = *quite a bit*, 4 = *extremely*).

Motivation was measured at the start of each visit via the success motivation and intrinsic motivation scales developed and validated by Mathews, Campbell, and Falconer (2001). Each subscale consists of seven items responded to on a 5-point Likert type scale with identical anchors to those described above.

3.3.11. Statistical Analyses

Unless otherwise noted, data are shown as mean ± SD. Four participants in the sample of 17 did not perform the 65% PPO TTE test after the 30 minute break (see Study design and procedures). All analyses up to the 30 minute break therefore included the full sample. All analyses involving data after the 30 minute break included only those who completed both TTE tests. Following parametric checks, summated and average physical training loads were assessed using independent *t*-tests. Two-way mixed model (Group x Visit) multivatiare analysis of variance (MANOVA) was used to assess BRUMS ratings. In addition, two-way mixed model analysis of variance (ANOVA) was carried out to assess motivation, TTE at 65% PPO and 80% PPO, end exercise RPE, end exercise heart rate, mean cadence, and end exercise lactate during the pre and post-intervention visits. These were also used to assess heart rate and lactate before the TTE test at 65% PPO, and HRV before each TTE test. The between-subjects factor was group (BET vs. Placebo) and the within-subjects factor was test (Pre-visit vs. Post-visit). Reaction time, and number of errors made during the Stroop colour word task were analysed using a 2 x 2 x 4 (Group x Visit x Task) mixed model ANOVA for data involving all individuals completing both TTE tests. A 2 x 2 x 2 (Group x Visit x Task) mixed model ANOVA was used to analyse reaction time and number of errors for the full sample of individuals completing the 80% PPO TTE test. Spontaneous eye blink rate was analysed using a 2 x 2 x 5 (Group x Visit x Task) mixed model ANOVA for individuals completing both TTE tests. A 2 x 2 x 3 (Group x Visit x Task) mixed model ANOVA was used to analyse eye blink rate for the full sample of individuals completing the 80% PPO TTE test. If assumptions of sphericity were violated the Greenhouse-Geisser correction was used while Tukeys HSD post hoc tests were calculated where appropriate.

The iso-time variables of RPE and heart rate were analysed at 0% (first minute), 50%, and 100% (final full minute completed) for the 80% PPO TTE test using a 2 x 2 x 3 (Group x Visit x Iso-time) mixed model ANOVA. The iso-time variables of RPE and heart rate, were analysed at 0% (first minute), 25%, 50%, 75% and 100% for the 65% PPO TTE test using a 2 x 2 x 5 (Group x Visit x Iso-time) mixed model ANOVA. These variables were measured at the selected time-points to allow a within-group comparison of the temporal changes arising throughout the TTE tests. To obtain this iso-time data, the value of each parameter at 100% iso-time was established by identifying the shortest TTE test accomplished by each individual over their two respective trials. The value for each recorded variable during the final full minute of the shortest TTE test was then compared to that of the equivalent minute of the longer test intensity. This was procedure was performed separately for each exercise intensity. For the 65% PPO TTE test, the minute identified as 100% iso-time was multiplied by 0.25, 0.5 or 0.75 to obtain the point respectively corresponding to 25%, 50% and 75% iso-time. Each point was then rounded to the nearest measured value. For the 80% PPO TTE test, the minute at 100% iso-time was only multiplied by 0.5 to establish 50% iso-time. Values at 0% were based on those at the end of the first full minute of each TTE test. Statistical significance was set at $p < 0.05$ (two-tailed). All data analysis was conducted with the statistical package for social sciences (SPSS version 20).

Magnitude based inferences were analysed (Batterham & Hopkins, 2006) to indicate the practical effect of BET on each TTE test, and at every measurement of iso-time RPE. The practical effect of BET on TTE, was established by first calculating the within participant differences between the pre and post-intervention visit for each group. These differences were then subtracted to provide an overall difference between groups. This procedure was also performed at each iso-time point to assess the practical effect of BET on RPE. Standardized values of Cohen's *d* (Cohen, 1988) provide an estimate of effect size throughout.

Thresholds for small, moderate, and large effect sizes were set at 0.2, 0.5, and 0.8, respectively (Cohen, 1988). Precision of the estimate is provided by ± 90% confidence intervals (Hopkins, Marshall, Batterham, & Hanin, 2009). This estimate indicates the plausible range within which the true population effect for each measure may reside

(Cumming, 2014). As recommended by Batterham and Hopkins (2006), to establish the practical significance of each measure, the smallest worthwhile change between groups was based on a small Cohen's *d* effect size (>0.2). The statistical likelihood of meeting the smallest worthwhile change for each measure was calculated using a published spreadsheet (Batterham & Hopkins, 2006). Qualitative descriptors of the effect of BET in relation to the smallest worthwhile change were assigned as follows: <1%; *almost certainly not*; <5% *very unlikely*; <25% *unlikely*; 25-75% *possible*; 75-95% *likely*; 95-99% *very likely*; >99% *almost certain*. Where the chance of benefit or harm were both >5%, the true effect was deemed *unclear* (Batterham & Hopkins, 2006).

3.4. Results

3.4.1. Group Characteristics, Session RPE, BET Participation, and Mood and Motivation

Age, $\dot{V}O_{2max}$, PPO, and weekly training hours were not statistically different between groups (see Table 3.1). This was also the case for summated training load $t(14) = -1.66$, $p = .12$, and average training load, $t(14) = 1.13$, $p = .28$. Due to server difficulties, four weeks of participation data was lost for three participants. With these participants excluded, 91.6 ± 11.3% of the BET sessions were completed during the intervention. A Group x Visit MANOVA revealed that no main effects for group, $F(2, 30)$, = 1.31, $p = .33$, or visit, $F(2, 30$, = 0.71, $p = .65$, and no Group x Visit interactions, $F(2,30)$, = 0.73, $p = .64$, were present for BRUMS subscale ratings. Univariate tests also revealed no differences on any subscales (See Table 3.2). Similarly, no main effects or Group x Visit interactions were evident for ratings of success motivation or intrinsic motivation. Together, this indicates that each group commenced both visits in similar physical condition and with similar levels of mood and motivation.

Table 3.1. Mean ± SD participant group characteristics for all individuals (80% PPO TTE test) and individuals who continued to the 65% PPO TTE test

	80% PPO			65% PPO		
	Placebo (n = 8)	BET (n = 9)	p value	Placebo (n = 6)	BET (n = 7)	p value
VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	50.5 ± 4.1	54.7 ± 8.3	= .22	51.8 ± 3.76	55.6 ± 8.75	= .35
PPO (W)	297 ± 61	315 ± 64	= .57	316 ±60	330 ± 56	= .66
Age (years)	45.8 ± 11.6	40.0 ± 11.8	= .33	43.7 ± 11.9	38.9 ± 13.2	= .51
Training (hours·week)	6.25 ± 2.30	6.00 ± 1.22	= .78	6.50 ± 2.65	6.00 ± 1.41	= .67

Note: VO_{2max} = maximum oxygen uptake; PPO = peak power output; BET = brain endurance training

Table 3.2. Mean ± SD ratings for BRUMS subscales and success and intrinsic motivation

		Placebo		BET		
		Pre	Post	Pre	Post	P value
BRUMS	Anger	0.00 ± 0.00	0.13 ± 0.36	0.00 ± 0.00	0.22 ± 0.67	= 0.72
	Confusion	0.38 ± 0.52	0.13 ± 0.35	0.44 ± 1.01	0.33 ± 0.71	= 0.77
	Depression	0.00 ± 0.00	1.0 ± 2.8	0.22 ± 0.66	0.22 ± 0.44	= 0.31
	Fatigue	2.13 ± 1.8	2.13 ± 1.80	1.22 ± 1.30	0.56 ± 0.90	= 0.95
	Tension	1.25 ± 1.04	1.00 ± 1.70	0.90 ± 1.36	0.22 ± 0.71	= 0.92
	Vigor	9.38 ± 2.30	10.13 ± 3.00	9.00 ± 3.24	8.22 ± 1.79	= 0.39
Motivation	Success	15.4 ± 6.0	18.9 ± 5.2	17.3 ± 6.1	18.2 ± 5.3	= 0.30
	Intrinsic	24.4 ± 2.2	22.9 ± 3.1	25.2 ± 2.2	21.7 ± 5.0	= 0.26

Note. BET = brain endurance training; Pre = pre-intervention visit; Post = post-intervention visit; p values = univariate interaction terms

3.4.2. Effect of BET on TTE at 80% and 65% PPO

A main effect across visits was evident for TTE at 80% PPO, $F(1, 15) = 10.36$, $p = .006$. There was no main effect between groups however, $F(1, 15) = 0.76$, $p = .40$, and no significant Group x Visit interaction, $F(1, 15) = 0.81$, $p = .86$. At this intensity, TTE was reduced from pre-test (475 ± 211 seconds) to post-test (421 ± 164 seconds) following BET, and placebo (pre-test 634 ± 516 seconds, post-test 573 ± 479 seconds). Though TTE was reduced in both groups after the intervention, the reduction in BET was 6.4 seconds less

(d = -0.02, 90% CI [69.6, -56.9]) than placebo (see Figure 3.2). This equated to an *unclear* practical effect of BET (beneficial/trivial/harmful%; 4/90/6%).

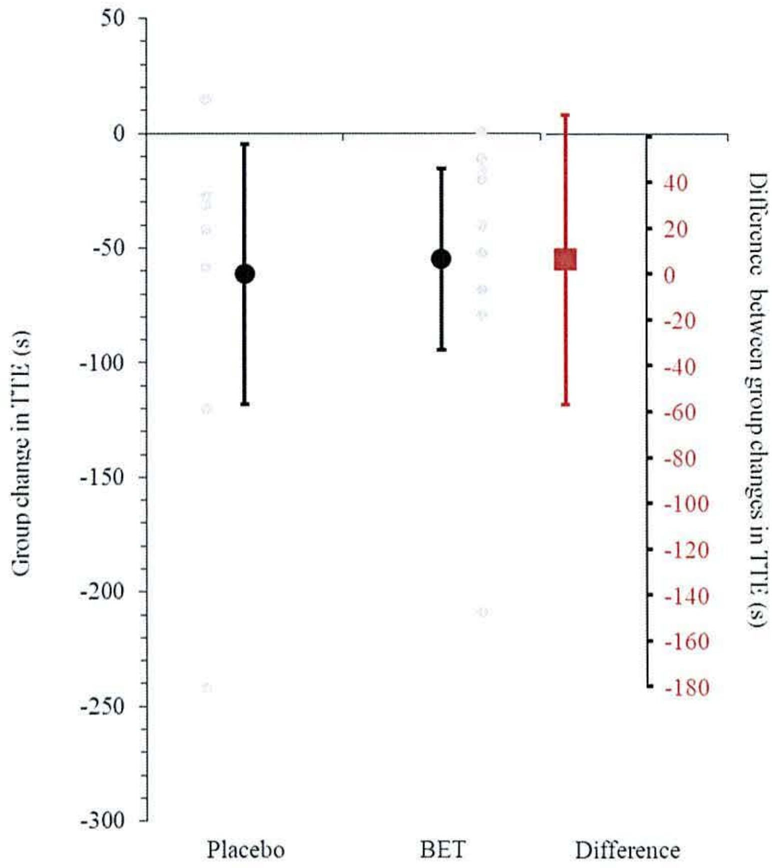

Figure 3.2. Mean (± 90% *CI*) pre-intervention to post-intervention change in TTE at 80% PPO for placebo and BET (black dots) and individual pre-intervention to post-intervention changes within each group (grey dots). Floating secondary y-axis denotes overall difference between group changes (red square).

At 65% PPO there was no main effect of TTE across visits, $F(1, 11) = 4.15, p = .07$; there was also no main effect between groups, $F(1, 11) = 0.34, p = .57$. Additionally there was no significant Group x Visit interaction, $F(1, 11) = 2.96, p = .11$. However, TTE did increase following BET at this intensity (pre-test 1377 ± 322 seconds, post-test 1626 ± 438 seconds). In comparison, TTE in the placebo group was similar across tests (pre-test 1645 ± 648 seconds, post-test 1666 ± 540 seconds). After BET, the improvement in TTE was therefore 229 seconds greater ($d = 0.47$, 90% CI [-10, 467]) than that of the placebo group (see Figure 3.3). This signified a practical effect of BET on TTE that was *likely beneficial* (83/15/2%).

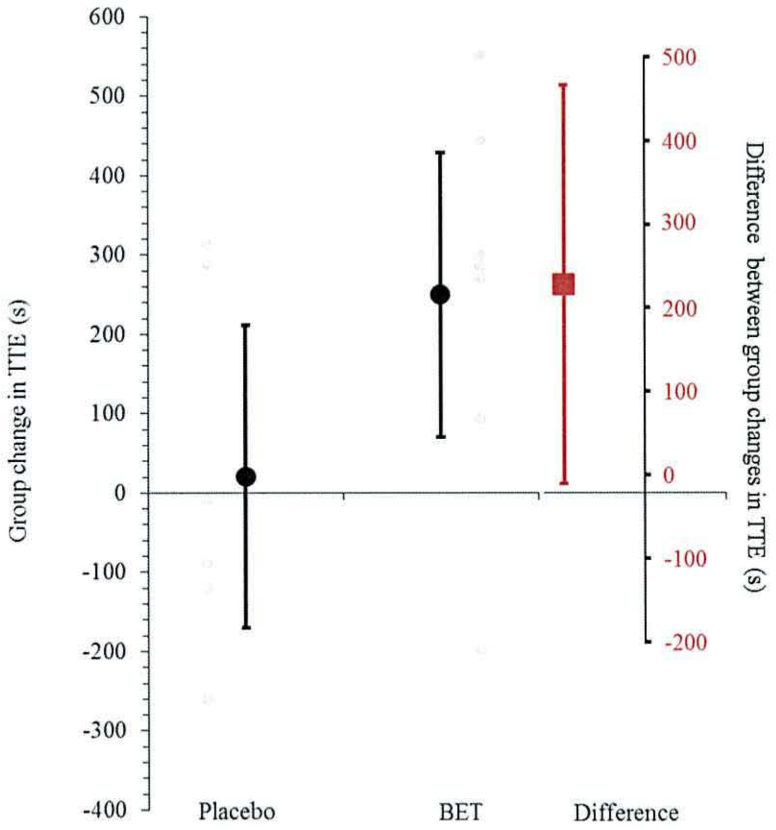

Figure 3.3. Mean (± 90% CI) pre-intervention to post-intervention change in TTE at 65% PPO for placebo and BET (black dots) and individual pre-intervention to post-intervention changes within each group (grey dots). Floating secondary y-axis denotes overall difference between group changes (red square).

3.4.3. Effect of BET on Mean Cadence, RPE at Exhaustion, and Heart Rate and Blood Lactate Concentration at Exhaustion, and Before the 65% PPO TTE Test

No Group x Visit interactions or main effects were evident for mean cadence during both TTE tests (see Table 3.3). This was also the case for RPE at exhaustion. Similarly no

Group x Visit interactions and main effects of test were evident for blood lactate concentration at exhaustion at either intensity. Moreover, no Group x Visit interactions or main effects of test were detected for heart rate at exhaustion at 80% PPO; a Group x Visit interaction was however present for heart rate at exhaustion at 65% with following up tests indicating that heart rate was significantly greater at exhaustion following BET.

Table 3.3. Mean ± SD cadence during each TTE test and additional physiological and psychophysiological variables at the end of both TTE tests

		Placebo		BET		
		Pre	Post	Pre	Post	*p* value
80% PPO	Mean Cadence (RPM)	81.1 ± 6.7	81.2 ± 8.1	84.0 ± 5.5	83.4 ± 6.9	= .71
	End RPE	9.70 ± 1.20	9.50 ± 0.90	9.78 ± 0.71	9.50 ± 0.83	= .71
	End Lac (mmol · l)	8.80 ± 1.50	8.43 ± 1.94	8.80 ± 1.74	9.00 ± 2.10	= .08
	HR_{max} (beats · min^{-1})	164 ± 9	161 ± 10	165 ± 15	165 ± 17	= .10
65% PPO	Mean Cadence (RPM)	85.7 ± 8.0	82.5 ± 10.0	85.3 ± 9.7	85.2 ± 9.6	= .34
	End RPE	9.83 ± 0.42	9.83 ± 0.42	9.14 ± 1.11	9.57 ± 0.53	= .39
	End Lac (mmol · l)	6.20 ± 2.41	6.25 ± 1.62	7.50 ± 2.50	8.17 ± 2.68	= .49
	HR_{max} (beats · min^{-1})	163 ± 14	159 ± 13	171 ± 14[b]	174 ± 17[a,b]	= .03

Note . BET = brain endurance training; 80% PPO = time to exhaustion test at 80% peak power output; 65% PPO = time to exhastion test at 65% peak power output; RPM = revolutions per minute; End Lac = end exercise lactate; HR_{max} = end exercise heart rate; End RPE = end exercise percpetion of effort; Pre = pre-intervention visit; Post = post-intervention visit; *p* value = interaction term

[a] = significantly greater than pre-intervention visit; [b] = significantly greater than corresponding visit in placebo group

No significant Group x Visit interactions were evident in heart rate and blood lactate before the TTE at 65% PPO. This signifies that all participants had received sufficient rest following the 80% TTE test 90 minutes earlier (see Table 3.4).

Table 3.4. Mean ± SD measured physiological variables before the TTE test at 65% PPO

	Placebo		BET		
	Pre	Post	Pre	Post	*p* value
Pre Lac (mmol · l)	1.72 ± 0.32	1.52 ± 0.55	1.81 ± 0.33	1.87 ± 0.40	= .30
HR_{pre} (beats · min^{-1})	62.7 ± 9.2	59.3 ± 3.6	63.7 ± 9.6	67.3 ± 16.8	= .19

Note . Pre Lac = pre exercise lactate; HRpre = resting pre exercise heart rate; Pre = pre-intervention visit; Post = post-intervention visit

3.4.4. Effect of BET on Iso-time RPE and Heart Rate During the TTE Tests

At 80% PPO, no significant Group x Visit x Iso-time interaction was identified for RPE, $F(2, 30) = 1.92, p = .17$ (see Figure 3.4), with no significant Group x Visit interaction, $F(1, 15) = 0.03, p = .87$. Furthermore the practical effect of BET on iso-time RPE during the TTE test at 80% PPO was shown to range from *unclear* to *possibly harmful* (see Table 3.5).

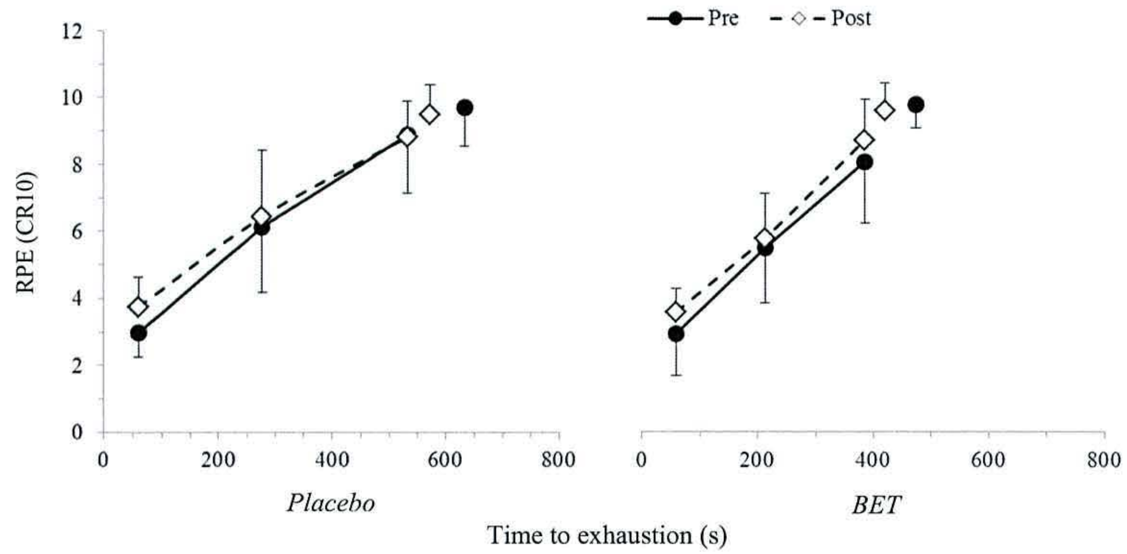

Figure 3.4. Mean (± *SD*) effects of placebo and BET on RPE at 0%, 50%, and 100% iso-time during 80% PPO time to exhaustion test. Unconnected markers represent RPE at exhaustion.

Table 3.5. Practical effect of BET on iso-time RPE during the 80% PPO TTE test

	Mean ± SD Pla Pre-Post Difference (Borg 0-10)	Mean ± SD BET Pre-Post Difference (Borg 0-10)	Difference BET - Pla (Borg 0-10)	90% CI (Borg 0-10)	ES (*d*)	Magnitude (Beneficial/Trivial /Harmful%)	Practical Inference
RPE 0% Iso-time	0.75 ± 0.46	0.67 ± 0.90	-0.08	[-0.70, 0.54]	0.11	(43/31/26)	*Unclear*
RPE 50% Iso-time	0.31 ± 0.80	0.22 ± 0.62	-0.09	[-0.69, 0.51]	0.13	(49/3/48)	*Unclear*
RPE 100% Iso-time	-0.06 ± 0.9	0.67 ± 0.97	0.72	[-0.10, 1.56]	-0.75	(4/10/86)	*Possibly Harmful*

Note. RPE = perception of effort; Pla = Placebo; BET = brain endurance training; 90% CI = 90% confidence intervals; ES (*d*) = Cohens *d* effect size; Pre = pre-intervention visit; Post = post-intervention visit

No significant Group x Visit x Iso-time interaction was evident for RPE during the TTE test at 65% PPO, $F(4, 44) = 1.00, p = .42$ (see Figure 3.5). Moreover there was no

Group x Visit interaction $F(1, 11) = 2.13, p = .17$. A magnitude based inferences approach at each measured iso-time point revealed a *likely beneficial* effect of BET on RPE at 50% iso-time. The practical effect of BET at all other iso-time points during this test were however *unclear* (see Table 3.6).

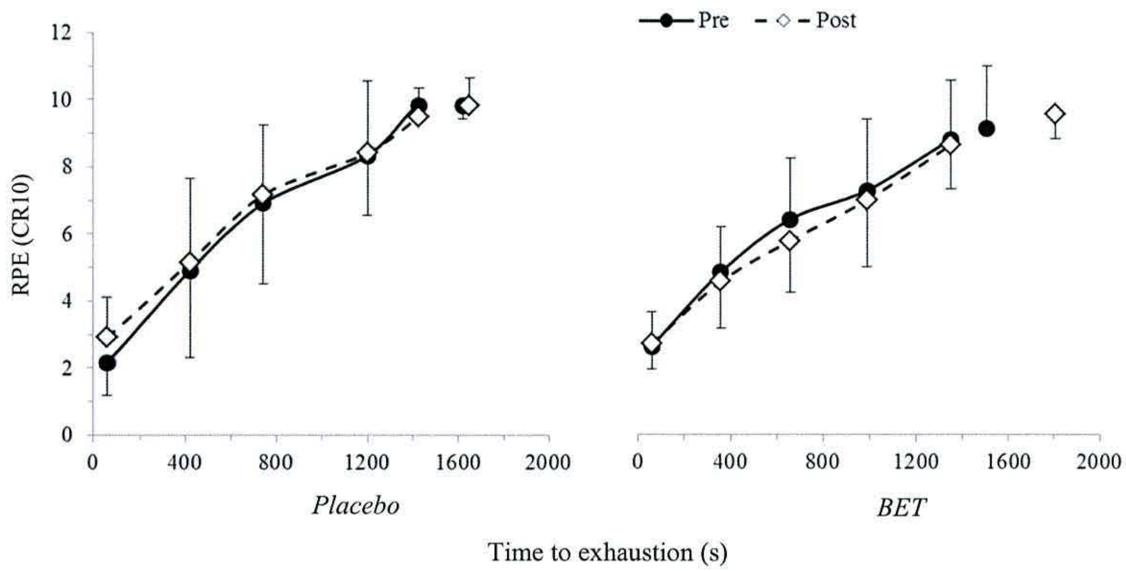

Figure 3.5. Mean (± *SD*) effect of placebo and BET on RPE at 0%, 25%, 50%, 75%, and 100% during 65% PPO TTE test. Unconnected markers represent RPE at exhaustion

Table 3.6. Practical effect of BET on iso-time RPE during 65% PPO TTE test

	Mean ± SD Pla Pre-Post Difference (Borg 0-10)	Mean ± SD BET Pre-Post Difference (Borg 0-10)	Difference BET - Pla (Borg 0-10)	90% CI (Borg 0-10)	ES (*d*)	Magnitude (Beneficial/Trivial /Harmful%)	Practical Inference
RPE 0% Iso-time	0.75 ± 1.17	0.07 ± 0.73	-0.68	[-1.63, 0.27]	0.71	(81/12/7)	*Unclear*
RPE 25% Iso-time	0.25 ± 1.17	-0.29 ± 0.76	-0.54	[-1.51, 0.43]	0.33	(65/28/7)	*Unclear*
RPE 50% Iso-time	0.25 ± 0.88	-0.64 ± 0.63	-0.89	[-1.81, 0.03]	1.18	(95/4/1)	*Likely Beneficial*
RPE 75% Iso-time	0.08 ± 0.92	-0.29 ± 0.49	-0.37	[-1.09, 0.35]	0.52	(71/18/11)	*Unclear*
RPE 100% Iso-time	-0.33 ± 0.82	-0.14 ± 0.94	0.19	[-0.14, 0.33]	-0.21	(51/26/23)	*Unclear*

Note. RPE = perception of effort; Pla = Placebo; BET = brain endurance training; 90% CI = 90% confidence intervals; ES (*d*) = Cohens *d* effect size; Pre = pre-intervention visit; Post = post-intervention visit

There was no Group x Visit x Iso-time interaction for heart rate during the TTE test at 80% PPO, $F(2, 30) = 0.74, p = .49$, and no Group x Visit interaction, $F(1, 15) = 0.95, p = .35$.

A similar statistical pattern was evident at 65% PPO with no Group x Visit x Iso-time interaction detected, $F(4, 44) = 0.50$, $p = .74$. In addition there was no Group x Visit interaction present $F(1, 11) = 1.20$, $p = .30$.

3.4.5 Effect of BET on Eye Blink Rate at Baseline and Before and After Each TTE Test

Due to a long-term equipment malfunction, eye blink data is not available for 4 participants. All analyses were therefore conducted without these participants. All individuals took part in the 80% PPO TTE test. Accordingly, measures of eye blink rate at baseline and before and after this test were available for the full cohort, other than those affected by the equipment malfunction. At this intensity, no significant Group x Visit x Eye blink rate interaction was evident across these measurement points, $F(2, 22) = 1.12$, $p = .35$. At 65% PPO, analysis only included those individuals who completed all 5 measurement points for eye blink rate during each visit. At this intensity a Group x Visit x Eye blink rate (2 x 2 x 5) interaction was present, $F(4, 36) = 4.03$, $p = .008$. Group x Visit (2 x 2) follow up tests at each time point indicated a significant interaction at baseline ($p = .05$), with eye blink rate lower following BET and greater following placebo. Conversely, no statistical differences were evident in eye blink rate before the 80% PPO TTE test ($p = .12$), after the 80% PPO TTE test ($p = .65$), or after the 65% PPO TTE test ($p = .73$). A trend towards statistical significance was however evident before the 65% PPO TTE test ($p = .07$), with eye blink rate greater following BET, compared to the placebo group.

3.4.6. Effect of BET on Cognitive Performance, Reaction Time and Heart Rate Variability

Correct responses and reaction time were measured during the four Stroop tasks that were carried out during each visit. When the full sample of individuals completing the 80% PPO TTE test were analysed, a Group x Visit x Response (2 x 2 x 2) ANOVA revealed no interaction $F(1, 15) = 0.86$, $p = .37$. This was also the case for reaction time, $F(1, 15) = 0.06$, $p = .80$. For individuals who completed both TTE tests, a Group x Visit x Response (2 x 2 x 4) ANOVA for correct responses during the Stroop tasks did not reveal any interaction, $F(3, 33) = 1.14$, $p = .35$). Similarly, a Group x Visit x Reaction time ANOVA revealed no significant interaction, $F(3, 33) = 0.19$, $p = .91$, during the same tasks.

In addition, HRV was measured throughout the Stroop task that immediately preceded each TTE test. This data was lost for one participant in the placebo group prior to the 80% PPO TTE test. At this intensity, no Group x Visit interaction was present in HRV during the Stoop task, $F(1, 14) = 0.00$, $p = .99$. The Stroop task before the 65% PPO TTE test was performed without those individuals who only completed the 80% PPO test. At this intensity, once more no Group x Visit interaction was present in HRV during the Stoop task, $F(1, 11) = 0.62$, $p = .45$. Together, this infers that cognitive effort was not significantly altered during the Stroop task as a result of BET.

3.5. Discussion

It was hypothesized that a six week intervention of BET would reduce RPE during endurance exercise and increase TTE. Contrary these hypotheses, BET did not significantly reduce RPE during endurance exercise at either 80% PPO, or 65% PPO. Furthermore TTE was not significantly different following BET at either exercise intensity. Nonetheless, TTE was increased in six out of seven individuals at 65% PPO following BET, leading to an overall improvement in TTE of 18% at this intensity compared to placebo. Accordingly, BET had a practical effect on TTE at 65% PPO that was deemed to be *likely beneficial* when considered against the designated threshold for a smallest worthwhile change.

The unique concept that a protocol of BET may reduce RPE and enhance TTE was based on the synthesis of a number of established research areas. In particular, this concept was designed to capitalize on the neural adaptations that occur following many cognitive training protocols (Ceccarelli et al., 2009; Draganski et al., 2006; McNab et al., 2009) and the neuro-cognitive links between physical and cognitive activity (Cotman et al., 2007), and RPE (Brownsberger, Edwards, Crowther, & Cottrell, 2013; Marcora et al., 2009). Accordingly, the present BET intervention was designed to target the ACC because this neural structure has been linked to both cognitive and physical effort (Critchley et al., 2005). Although BET did not cause a significant reduction in RPE during either TTE test, it did have a *likely beneficial* practical effect on RPE at 50% iso-time during the TTE tests at 65% PPO. In conjunction with this, eye blink rate was found to be significantly altered following BET with a statistical difference between groups at baseline and a non-significant statistical trend towards an increased eye blink rate following BET, prior to the 65% PPO TTE test.

Eye blink rate was used as a surrogate marker of dopamine activity as effort based ACC activation is suggested to be mediated by this neurotransmitter (Lorist et al., 2005; Salamone, Correa, Farrar, Nunes, & Pardo, 2009). Using more direct neural measures of dopamine activity previous studies have reported increases in dopamine following cognitive training interventions of a similar duration to the present one (Bäckman et al., 2011; McNab et al., 2009). This bolsters the possibility that the changes observed in eye blink rate in the current investigation are reflective of genuine dopaminergic fluctuations.

Increases in eye blink rate are proposed to indicate elevated dopaminergic activity (Aarts et al., 2012; Colzato et al., 2007: Colzato et al., 2009). Although the greater eye blink rate following BET before the 65% PPO TTE test was non-significant, the statistical trend that emerged therefore hints at the possibility that targeting the ACC with BET altered the ACC – dopaminergic neuro-circuitry in some way. Accordingly this may have facilitated the *likely* beneficial reduction in RPE at 50% iso-time and the ensuing *likely* practical, although non-statistically significant, enhancement in TTE at this intensity. Indeed, the 18% increase in TTE at 65% PPO in the present study is comparable to the 17% increase in TTE compared to placebo, that was reported alongside a reduction in RPE after dopamine activity was manipulated pharmacologically using the psychostimulant modafinil (Jacobs & Bell, 2004). Such a finding also somewhat conforms to reports from rodent studies that have noted attenuations in effortful behaviour following dopamine receptor blockade (Schweimer & Hauber, 2006). Despite this, it is important to emphasize that these assertions cannot be reliably confirmed unless more comprehensive cerebral measurements, and statistically significant findings, are established.

Although the practical effect of BET on RPE at 65% PPO was deemed as *likely* at 50% iso-time, it should be acknowledged that the effect on RPE at all other iso-time points was *unclear*. Moreover RPE following BET was almost identical to placebo at 100% iso-time at this intensity. This latter observation has important implications for the psychobiological model of endurance performance. This is because at first glance it suggests that a reduction in RPE may not always be necessary for an increase in TTE. However, it is conceivable that RPE was altered in a manner that had not previously been considered. For example, despite this similarity in RPE between BET and placebo at 100% iso-time, the increase in TTE was still 18% greater following BET. As such, this may indicate that BET permitted participants to tolerate very high levels of effort for longer during the latter part of the TTE test. Specifically this would mean that although RPE was near maximal, the point at which continuation in the task appeared to be impossible was delayed, regardless of whether RPE was lower or not (Wright, 2008). Considering the statistical trend for increased eye blink rate before exercise at 65% PPO following BET, possible support for this increased tolerance can be gleaned from the fact that elevated dopamine activity has been associated with an increase in motivated behaviours (Bello et al., 2011; Treadway et al, 2012; Trifilieff et al., 2013), including persistence (Salamone et al., 2009) and the willingness to exert effort during challenging situations (Salamone & Correa, 2012; Wardle et al., 2011).

In contrast to the 65% TTE test, there was no evidence of a difference in endurance between groups at 80% PPO following BET. Moreover, there was no significant difference in eye blink rate between BET and the placebo group prior to this 80% PPO TTE test. On one hand this supports the plausibility that the non-significant 18% increase in TTE at 65% PPO following BET may have been driven by increased pre-exercise dopamine activity. On the other, it is difficult to explain why eye blink rate was not different before exercise at 80% PPO; primarily because this preceded the 65% PPO TTE test for all participants during both visits. One explanation could be that BET reinforced the ability to maintain or elevate dopaminergic activity following prior fatiguing exercise. For example, pre-task fatigue is thought to reduce subsequent ACC activation, but enhanced dopamine activity is found to compensate for this ACC related fatigue (Moeller, Tomasi, Honorio, Volkow, & Goldstein, 2012). A further and somewhat related explanation for this difference in performance could be associated with the motivational effects of dopamine (Satoh et al., 2003). Specifically, as exercise duration increases, psychological factors such as motivation are thought to become more influential (Burnley & Jones, 2007). Participants in the present study cycled for approximately 400% longer at 65% PPO in comparison to 80% PPO; hence the former intensity likely required more motivation to persist in the face of increasing effort as the task progressed. Given the aforementioned interplay between dopamine, motivation and effort (Salomone et al., 2009; Treadway et al, 2012; Trifilieff et al., 2013), the seemingly greater pre-task eye blink rate at 65% PPO following BET may therefore suggest a dopamine mediated increase in motivation to persist with the task (Moeller et al., 2012; Salomone et al., 2009).

It is also apparent following the intervention that not only was there no difference in TTE between groups at 80% PPO; but TTE for both groups actually decreased. A number of reasons can be suggested for this. Specifically, it is possible that the addition of regular demanding cognitive activity to a normal physical training regimen caused detrimental neural alterations. Indeed reduced dopamine activity is associated with cognitive fatigue (Lorist et al., 2005). Moreover a reduction in dopamine and a concomitant increase in serotonin is proposed to elicit physical fatigue and overreaching (Meeusen, Watson, Hasegawa, Roelands, & Piacentini, 2007). The combination of frequent demanding cognitive activity and physical training may therefore have exacerbated adverse perturbations in these neurotransmitters during the intervention. Correspondingly, eye blink rate was significantly reduced at baseline following BET. As such this may indirectly infer that dopamine activity was in fact lower after BET, thus hinting at this overreaching effect.

While plausible, an overreaching effect cannot explain why TTE was also reduced in the placebo group. Moreover, a similar finding was not evident at 65% PPO. Alternatively therefore, this reduction in TTE at 80% PPO may have been a consequence of experimental design. For instance it is likely that during the post-intervention visit participants were more familiar with the requirements of the experimental protocol. This could have inflicted one of two important effects. Firstly, they may have exercised in a more reserved manner during the initial 80% PPO TTE test to enable them to cope more effectively with the latter 65% PPO TTE test. However, all participants still terminated exercise at a maximum or near maximum RPE. With this in mind, knowledge of the impending 65% PPO TTE test may have instead caused participants to catastrophize their RPE during the initial test at 80% PPO (Lukkahatai & Saligan, 2013); hence why they reached reach maximum RPE sooner. Regardless, either of these possibilities would confound the findings of the 80% PPO test. As such a further BET investigation focusing exclusively on exercise at this intensity may be warranted.

To further clarify the effects of BET, cognitive effort was assessed before each TTE test and cognitive task performance was measured before and after each TTE test. To obtain an objective measure of cognitive effort, HRV was measured in the mid-frequency domain (Capa et al., 2011). Similar to RPE, no statistical differences in HRV were observed at 80% PPO or 65% PPO. This manipulation check implies that BET did not alter ACC activity (Critchely, 2003) or effort during the cognitive task. This finding could however also be a consequence of the methodological design. For example, pre and post-intervention changes in cognitive performance are routinely used to establish the effect of an intervention in cognitive training studies (Jaeggi et al., 2008; Klingberg, Forssberg, & Westerberg, 2002). In this case, a Stroop task was selected to assess the effect of BET because of its ability to target the ACC whilst remaining sufficiently dissimilar to the tasks used during the BET protocol (Peterson et al., 2002). Despite this, no changes were detected after BET for both correct responses and reaction time on the Stroop task. Indeed, the number of correct responses throughout both visits in both groups was high. Moreover, reaction time was significantly increased throughout visits. These findings depict the opposite of what might be expected during a demanding cognitive task (Boksem et al., 2006). As such, the selected Stroop task may not have instigated the cognitive demand necessary to reveal an adaptation to cognitive effort. Furthermore it is possible that the 15 minute duration of each Stroop task may have been too brief to elicit cognitive demand (Kato et al., 2009).

During the investigation a number of psychological and physiological variables were also recorded. Accordingly, no statistical differences in mood or motivation occurred across either group or visit. This suggests that both groups commenced their visits in similar psychological state regardless of the condition that they were assigned to. Likewise, no statistical differences were discernable in training load between groups during the intervention. Importantly this manipulation check indicates that physical training effects throughout the six week intervention did not influence the findings. Heart rate was also measured during the TTE tests at both intensities. Moreover mean cadence was recorded during each TTE test, and heart rate and lactate were recorded at the end of each test. As no statistical differences in end lactate were found at either intensity, physiological influences relating to this variable can be ruled out when considering the *likely* beneficial effect on endurance at 65% PPO. Furthermore mean cadence was not statistically different between visits. This provides some assurance against differences in muscle recruitment patterns and cycling efficiency (Dantas et al, 2009). However, although no iso-time measurements of heart rate were statistically different following BET at either intensity, there was a significant interaction for final heart rate during the 65% TTE test. Specifically heart rate was greater following BET. In one way this is not surprising as ACC activation has also been associated with heart rate (Critchley, 2003) and in particular sympathetic activation of the autonomic system (Luu & Posner, 2003). Hence, while this may be indicative of a physiological influence on endurance, it does not rule out the possibility that this influence was inadvertently exerted by BET. Moreover, given the link between heart rate and ACC activation, this finding may actually be supportive of the success of the BET intervention; not least because low dose dopamine infusions have recently been found to increase heart rate in humans (Niewinski, Tubek, Banasiak, Paton, & Ponikowski, 2014).

Since this was the first investigation of an original concept, a number of limitations must also be taken into account. In particular, the relatively small sample size may have contributed to an inability to detect statistical changes in RPE, TTE and eye blink rate at 65% PPO. Small sample sizes have been documented as a problem in cognitive training research (Craik & Rose, 2012); however the demanding nature of such interventions makes it difficult to avoid this limitation. Moreover, the importance of acknowledging findings obtained from novel interventions that consist of small sample sizes has recently been advocated by Ploutz-

Snyder, Fiedler, and Feiveson (2013). This acknowledgment becomes even more pertinent when the *likely* practical benefit of BET at 65% PPO is considered (Batterham & Hopkins, 2006).

The null statistical findings of the present study could also be a result of the BET protocol design itself; particularly because this was the first known intervention of its type. For instance, this study exclusively targeted the ACC because cognitive and physical effort appear to be connected by this neural structure (Critchley et al., 2003; Marcora et al., 2009). Nevertheless, alternative neural regions such as the anterior insula are also associated with physical effort (Williamson, et al., 2002), while the basolateral amygdala, has an important role in the neural circuitry of physical effort in rodent models (Floresco & Ghods-Sharifi, 2006). Confining BET to cognitive tasks that stimulate the ACC may therefore have limited the scope for reducing RPE and increasing TTE. Also, to obtain an appropriate balance between participant adherence to the BET protocol and the frequent experience of high cognitive demand, each BET session during the first two weeks was restricted to a duration of 30 minutes. Hence, it is possible that this did not achieve the extent of cognitive demand necessary to stimulate the ACC. Similarly, some clinical cognitive training interventions persist for longer than the present six week protocol (cf. Jak, Seelye, & Jurick, 2013). As such, it may be that individuals must engage in BET for longer than anticipated in order to provoke sufficient neural adaptations. Lastly, it is evident that the mean age of the current sample is more representative of masters' athletes. Given the relatively diverse outcomes between older and younger age groups when involved in cognitive training programmes (Dahlin, Nyberg, Bäckman, & Neely, 2008), it is possible that different findings may emerge when younger cohorts are investigated. It is therefore important that BET is implemented in younger adults to facilitate a more comprehensive appraisal of its efficacy. Similarly, the study of BET in advanced athletic populations, primarily elite, and sub-elite athletes is also necessary. This would provide a more concise clarification of the utility of BET in individuals who are already accustomed to frequent high levels of effort during physical endurance tasks.

As noted, some of the objective measures used in the current study, particularly HRV and eye blink rate, were indirect. Consequently, despite ample empirical support for these methods it cannot be assured that they measure, or satisfactorily detect, changes in their intended variable. Moreover because eye blink rate is a surrogate marker it is impossible to determine a precise mechanism by which BET may have increased dopamine activity. For instance, potential explanations include an increase in striatal dopamine production (Bäckman et al., 2011), an increase in dopamine receptor binding at the ACC (Lumme et al., 2007), and a reduction in dopamine re-uptake (Jacobs & Bell, 2004). Nevertheless, the effect of BET on direct measures of dopamine activity therefore provides an important focus for future research. Furthermore, despite the present lack of statistical evidence for the effect of BET on TTE and RPE, the *likely* practical effects that occurred at 65% PPO offer a promising platform for future BET research. As such, the concept of BET may be more effective with modified protocols; for example, alternative neural target regions, greater session durations, or longer BET interventions. Other suggestions include, protocols encompassing the simultaneous application of effortful physical training and BET. This is because the demand implemented by such a dual approach may facilitate greater effort related neural adaptation. Likewise, physical training performed immediately prior to or following each BET session should also be considered. Modifications such as these might therefore permit a more conclusive appraisal of the efficacy of BET in relation to RPE and physical endurance.

In summary, the practical findings of this initial implementation of BET depict an encouraging and potentially innovative method of targeting performance enhancement in endurance athletes. Although some measurement techniques were indirect, the outcome of this study hints at the importance of identifying and targeting specific neural structures that may alter RPE in order to enhance endurance. Moreover, the results tentatively re-affirm the importance of dopamine in the interplay between effort related processes and the ACC. The practically *likely beneficial* effect on RPE at 65% PPO also offers some support for the psychobiological model of endurance performance, and possibly demonstrates the importance of psychobiologically altering motivational factors in order to persist with physical tasks during extreme levels of effort. Further comprehensive research surrounding this novel endurance training paradigm should be developed in order to solidify the present findings and optimize the way that BET is implemented.

CHAPTER 4

The Hidden Face of Success: Subliminal Affective Facial Cues Alter RPE and Time to Exhaustion

4.1. Abstract

Purpose: Humans have a large capacity to process non-conscious visual information. Consequently, implicit visual affective cues are known to alter cognitive performance and cognitive effort outside of awareness. Although affect is frequently associated with physical endurance performance, the influence of non-conscious visual affective cues upon endurance performance and perception of effort (RPE) is presently unknown. Accordingly, this formed the focus of the present novel study. **Method**: Thirteen participants (mean ± *SD*: age 20.5 ± 1.5 years; $\dot{V}O_{2max}$ 55.2 ± 8.7 $ml \cdot kg^{-1} \cdot min^{-1}$) cycled to exhaustion at a constant load of 65% peak power output (PPO) on two occasions while they were subliminally primed with happy or sad human faces in a randomized, counterbalanced, crossover design. **Results**: A paired sample *t*-test revealed that time to exhaustion (TTE) was significantly (~14%) greater when participants were subliminally primed with happy faces versus sad faces (1556 ± 810 s vs. 1367 ± 604 s, $p < .05$). This difference in TTE was also *possibly* practically meaningful (difference%; 70%). In addition, this corresponded with a significantly lower RPE when happy faces were subliminally primed. **Conclusion**: This study is the first to demonstrate that subliminally presented affective visual cues can alter physical endurance and RPE outside of conscious awareness. This has important ramifications for endurance competitors who compete in situations that are laden with visual affective cues and also provides a platform for further investigation into the role played by implicit cues during endurance exercise; including their role in performance enhancement.

Descriptors: Implicit priming, endurance performance, affect, RPE, psychobiological model.

4.2. Introduction

The interplay between affective states and human behaviour has been a prominent topic of investigation within the cognitive sciences for over a century (Altarriba, 2012; Gendron & Barrett, 2009). During this time, a range of research areas have illustrated the various ways that affect can influence human behaviour (Nettle & Bateson, 2012). One research area that has recently received widespread attention in this regard is sport and exercise performance. Generally this research highlights that a clear relationship exists between affective states and sports performance (Beedie, Terry, & Lane, 2000; Davis, Woodman, & Callow, 2010; LeUnes, 2000). In particular, one aspect of this research has established that affect is related to endurance performance with positive affect associated with better performance and negative affect associated with comparatively worse performance (Lane, Davenport, & Stevens, 2010; Renfree, West, Corbett, Rhoden, & St Clair Gibson, 2011). Correspondingly, a link between affective states and endurance performance is now widely accepted (Lane, Beedie, Jones, Uphill, & Devonport, 2012; Stanley, Lane, Beedie, Friesen, & Devonport, 2012). Despite this acceptance surrounding affective states and endurance performance, the manner in which endurance may be influenced by affective states that are activated non-consciously is seemingly still unknown.

Traditionally it was assumed that affective states were conscious processes that were recognised and felt by the individual (Shervin, Paanksep, Brakel, & Snodgrass, 2012). However, along with research highlighting the extent to which human behaviour is generally influenced by implicit processes (Bargh, Golwitzer, Lee-Chai, Barndoller, & Troetschel, 2001; Bijleveld et al., 2009; Pessiglione et al., 2007), contemporary perspectives suggest that affective states can also be activated non-consciously (Berridge & Winkielman, 2003; Gendolla, 2012; Silvestrini & Gendolla, 2011b). The human information processing capacity of the non-conscious system is proposed to be considerably large in comparison to the limited capacity to process conscious information (Dijksterhuis & Nordgren, 2006). Hence, only a trivial amount of momentary information is brought to conscious attention. This means that the majority of this information is processed non-consciously (Merikle, Smilek, & Eastwood, 2001). More compellingly, this non-consciously processed information can influence behaviour in a manner that resembles conscious awareness of the same stimuli (Bargh et al., 2001; Pessiglione et al., 2007).

Conscious affective states have been shown to possess motivational properties when they occur in conjunction with tasks that require the mobilization of resources. During these circumstances affect is considered to influence the appraisal of task demand and the subjective experience of task related effort. Furthermore, this influence occurs congruently, meaning that a positive affective state leads to reduced appraisals of task demand and experienced effort whereas a negative affective state leads to elevated appraisals of task demand and experienced effort (Gendolla & Krüsken, 2001). Importantly, these findings have also been repeated when affective states are implicitly manipulated. For example, exposing individuals to implicit affective cues such as subliminally primed happy faces prompted greater willingness to mobilize effort during challenging cognitive activity in comparison to subliminally primed sad faces (Silvestrini & Gendolla, 2011b).

These implicitly activated affective appraisals of task demand correspond to the predictions made by motivational intensity theory (Brehm & Self, 1989) which postulates that subjective effort is proportional to appraised task demand, providing success is worthwhile and possible. Accordingly, the lower appraisal of task demand that is associated with positive affective states coincides with a reduced experience of effort during objectively easy tasks, whereas effort is more willingly tolerated as tasks become more difficult. Conversely, the increased appraisal of task demand that is associated with negative affect coincides with an elevated experience of effort during objectively easy tasks, whereas effort is more readily withheld as task difficulty increases (Gendolla & Krüsken, 2001).

The psychobiological model of endurance performance (Marcora, Bosio, & de Morree, 2008), based on motivational intensity theory (Brehm & Self, 1989) posits that individuals terminate endurance exercise voluntarily and that this decision is determined by perception of effort (RPE). Endurance exercise is therefore maintained until the effort required by the task exceeds the greatest amount of effort that the individual is willing to exert (i.e., potential motivation), or until maximal effort is considered to have been reached and continuation in the task exceeds the perceived ability of the individual (Marcora et al., 2008). In applying the preceding associations between affective states and effort to the psychobiological model of endurance performance it is possible that RPE may be influenced by implicit affective cues. As the psychobiological model of endurance performance predicts that any physiological or psychological factor affecting RPE and/or potential motivation will affect endurance performance (Marcora et al., 2008), the implicit exposure to affective cues could therefore be a pertinent, but presently unconsidered, determinant of endurance performance.

From an implicit perspective, approximately 90% of the human capacity to process non-conscious information is thought to be occupied by the visual system (Dijksterhuis & Nordgren, 2006). Correspondingly, a variety of potentially affective visual cues exist within sporting environments. These range from the words and pictures that are displayed on advertisement hoardings to the facial expressions of competitors, team mates and even spectators. Indeed, research has demonstrated that tournament favourites are more prone to choking when a trophy is on display during competitive finals (Bijleveld et al., 2011). Importantly, it has previously been confirmed that implicit visual cues are able to influence motor performance. For instance, subliminal masked priming has been shown to elicit increases in handgrip force (Aarts, Custers, & Marien, 2008; Pessiglione et al., 2007) and to enhance persistence on a powerball task utilizing repetitive activity of the hand muscles (Radel, Sarrazin, & Pelletier, 2009). Nonetheless, research documenting the influence of implicit priming upon dynamic endurance based tasks is limited to only two studies (Banting, Dimmock, & Grove, 2011; Hodgins, Brown, & Carver, 2006). Encouragingly, these studies demonstrated that motivationally orientated implicit priming permitted individuals to row faster (Hodgins et al., 2006), and to optionally spend more time cycling at submaximal intensities (Banting et al., 2011). However neither study investigated the influence of implicit affective priming. As such, the influence of implicit affective cues upon endurance performance is still unknown. In view of the substantial implications that exposure to implicit affective cues may have for endurance competitors it is therefore necessary that this influence is investigated.

Given the established links between affective states and sports performance, the aim of the present study was to explore the novel concept that exposure to implicit affective cues may alter RPE and physical endurance. Implicit affective states were manipulated by exposing the participants to subliminal affective cues in the form of happy or sad faces (Silvestrini & Gendolla, 2011b) as they cycled to exhaustion. A TTE test was used to provide a stable method of establishing the effects of subliminal affective priming on RPE and the limits to endurance without the confounding interference that can arise due to individual pacing (Hopkins, Schabort, & Hawley, 2001). This type of test has previously been shown to be a sensitive measure of endurance performance (Amman, Hopkins, & Marcora, 2007). It was hypothesised that TTE would be greater and RPE would be reduced when individuals were subliminally primed with happy faces compared to sad faces during endurance based cycling.

4.3. Method

4.3.1. Participant Characteristics and Ethics

Fourteen recreationally trained individuals volunteered to take part in the study. One female participant was excluded due to a computer malfunction that revealed one affective facial prime during the final visit. Hence 13 participants were included in the final data analysis [7 males, mean ± *SD,* age 20.1 ± 1.5 years, peak power output 328 ± 54 W, maximum oxygen uptake ($\dot{V}O_{2max}$) 60.4 ± 6.9 $ml \cdot kg^{-1} \cdot min^{-1}$; 6 females, mean ± *SD*, age 21.0 ± 1.6 years, peak power output 233 ± 34 W, maximum oxygen uptake ($\dot{V}O_{2max}$) 49.2 ± 6.5 $ml \cdot kg^{-1} \cdot min^{-1}$]. Participants were aged between 18 and 23 years old and engaged in individual or team based endurance exercise on a minimum of one occasion per week. This equated to an average training session duration of 81.6 ± 26.9 minutes. The study was approved by the ethics committee of the School of Sport, Health, and Exercise Sciences (SSHES), Bangor University. Accordingly, prior to taking part all participants completed an informed consent form along with a standard medical questionnaire to disclose their present state of health. This confirmed that participants were healthy and free from injury. Before providing informed consent, participants received an overview of the procedures and requirements of the study and were informed that it was a reliability study designed to test the accuracy of wireless electroencephalography in detecting the neural response to unanticipated computer stimuli. Consequently, participants were naive to the true aims of the study until its cessation. They were then debriefed and requested not to discuss it further. A payment of £30 (approximately $45 / €35) was given to all participants for their involvement.

4.3.2. Study Design and Procedures

The study consisted of a single blind, randomized and counterbalanced crossover design in which all participants visited the laboratory on four separate occasions. Trials were conducted at the same location, at a similar time of day, on the same electromagnetically braked cycle ergometer (Excalibur Sport, Lode, Groningen, Netherlands). Saddle and handlebar specifications on the cycle ergometer were adjusted to suit the preference of each participant. These specifications were then maintained for every visit thereafter.

During Visit 1, each participant completed the informed consent questionnaire and a checklist to ensure compliance with pre-task instructions; anthropometric measurements were then recorded. After this, an incremental ramp test was carried out on a cycle ergometer to establish peak power output (PPO) and $\dot{V}O_{2max}$. The incremental ramp test began with a two minute rest after which power output was increased by 25 W every minute until volitional exhaustion. Exhaustion was operationally defined as the voluntary cessation of the task by the participant or the inability to maintain a pedal frequency of 60 revolutions per minute (RPM) despite strong verbal encouragement. For the task, the ergometer was set in hyperbolic mode, which allows the power output to be set independently of pedal frequency over a range of 30-120 RPM and the participant was instructed to remain in the saddle at all times. $\dot{V}O_{2max}$ was measured breath by breath via a computerized metabolic gas analysis system (Metalyzer 3B, Cortex Biophysik, Leipzig, Germany) connected to an oro-(mouth) mask (7600 series, Hans Rudolph, Kansas City, MO). The device was calibrated before each test using a known concentration of gases and a 3.0 litre calibration syringe (Series 5530, Hans Rudolph). Heart rate was recorded 15 seconds from the end of the two minute rest using wireless chest strap radio telemetry (S610, Polar Electro, Kempele, Finland) and was measured every minute during the test thereafter. RPE was also recorded every minute during the test according to standard instructions using the 11 point Borg CR10 scale (Borg, 1998).

Visit 2 was a familiarisation session in which participants completed all questionnaires (see Psychological questionnaires) and the physical task that was to be used during Visits 3 and 4. Upon arrival for Visit 3 participants completed mood and motivation questionnaires (see Psychological questionnaires) followed by the cycling TTE test. For the TTE test, participants were positioned on the cycle ergometer (set to hyperbolic mode) and instructed to remain in the saddle at all times. The task began with a three minute warm up at 30% of the participants PPO. After three minutes the power output was automatically increased to a power output corresponding to 65% PPO. Pedal cadence was freely chosen between 60 – 100 RPM and was recorded every minute during the test, as was heart rate (see Additional physiological measures). RPE (see Measurement of effort) was recorded using the 11 point Borg CR10 at two minute intervals during the task. TTE was defined as the cycling time accrued from the onset of the 65% constant intensity test until the point at which either the participant voluntarily terminated the task or pedal cadence had fallen below 60 RPM for five consecutive seconds. No verbal encouragement was provided at any point during the TTE test so as to eliminate the superimposition of any extraneous verbal statements. To avoid bias from facial mimicry, the experimenter stood behind participants at all times (Tassinary, Cacioppo, & Vanman, 2007). Exactly three minutes after the cessation of the TTE test participants provided an earlobe sample of whole fresh blood for lactate analysis (see Additional physiological measures).

Throughout the TTE test participants were exposed to the computerized scanning visual vigilance task (see Scanning visual vigilance task). This computerized task commenced at the onset of the TTE test and stopped when the TTE test was voluntarily terminated. Corresponding to the randomized and counterbalanced visit allocation, either the happy or sad mood primes were subliminally delivered within the scanning visual vigilance task for the duration of the TTE test (see Subliminal priming procedure). During the TTE test the computer screen was placed at eye level 60 cm away from participants. After the TTE test and the lactate sample, participants completed the mood questionnaire for the second time.

All procedures during Visit 4 were identical to Visit 3, other than participants receiving the alternative affective prime. At the end of Visit 4, participants underwent a standardized funnelled debriefing procedure (Bargh & Chartrand, 2000). This was to probe for interpretation of the experimental hypothesis and awareness of the subliminal primes (see Funnelled debriefing procedure). If any participants alluded to a face within or before the black and white pattern they were further probed for gender, facial expression and any other details. After being fully debriefed, participants were thanked and then received their payment.

Visits 1, 2, and 3 were separated by a minimum of five days, while Visits 3 and 4 were separated by a minimum of five days and a maximum of 14 days. During this time, individuals were instructed to maintain their normal exercise programme. As instructed prior to each visit, participants preserved similar dietary patterns during the preceding 24 hours while consuming an amount of water equivalent to least 35 $ml \cdot kg^{-1}$ body weight and attaining at least 7 hours of sleep the night before. Participants also avoided any heavy exercise in the 24 hours prior to testing and refrained from the consumption of caffeine and nicotine in the 3 hour period leading up to each test. Finally, participants voided before each test and performed during all visits in similar clothing. Participants remained unaware of their TTE for the familiarization visit and for Visits 3 and 4 until the final debriefing procedure.

4.3.3. Scanning Visual Vigilance Task

The scanning visual vigilance task (Lieberman, Coffey, & Kobrick, 1998) was used in order to provide an effective method of delivery for the computerized subliminal mood primes during the TTE test. As cognitive effort has been shown to affect endurance performance and RPE (Marcora, Staiano, & Manning, 2009), this task was selected to minimize the amount of cognitive activity that was imposed upon participants during the TTE test. Participants were therefore simply requested to focus on the computer screen at all times and informed that a green circle of 3 cm diameter would randomly appear somewhere on the screen. The time that elapsed between each individual appearance of the circle was no shorter than 45 seconds, and no longer than 90 seconds. Participants were instructed that when the circle appeared they were not to respond and were to carry on cycling whilst maintaining focus upon the screen. The 3 cm green circle appeared at an identical time and screen location during each TTE test for all participants across visits.

4.3.4. Subliminal Priming Procedure

Corresponding to the allocated visit, happy or sad affective facial expressions were subliminally primed within the computerized scanning visual vigilance task throughout the TTE test. One prime was presented sequentially every 4996 ms. Each prime sequence consisted of a white fixation cross that was displayed on a black background in the centre of the screen (1000 ms). This was instantly followed by a facial expression (16 ms) that was backward masked by a briefly flashed black and white pattern (130 ms). Following the backward mask, the screen either remained black (3850 ms) or alternatively a green circle of 3 cm diameter appeared against the black background in a random location (3850 ms). The next prime sequence was commenced immediately after this. In order to prevent habituation to the affective facial expressions, two thirds of the prime sequences consisted of a neutral facial expression with the remaining one third consisting of the relevant affective facial expression (Silvestrini & Gendolla, 2011a). So as participants were exposed to the affective facial expression throughout the TTE test, it was ensured that two affective facial expressions were presented within every six prime sequences. The remaining four primes within each six prime sequence consisted of neutral facial expressions. The affective facial expressions consisted of a front perspective black and white human image taken from the Averaged Karolinska Directed Emotional Faces (ADKEF) database (Lundqvist & Litton, 1998). Half of the faces were male (MNES, MSAS, MHAS) and the other half were female (FNES, FSAS, FHAS). The priming programme was generated in E-prime software (E-Prime, Psychology Software Tools, Pittsburgh, PA) and the primes were presented on a 19` computer monitor with an aspect ratio of 16:9, a refresh rate of 60 Hz, and a 1280 x 720 pixel array.

4.3.5. Funnelled Debriefing Procedure

The funnelled debriefing procedure was administered as a manipulation check to ensure that participants were not consciously aware of the affective nature of the primes during the subliminal priming procedure. This method was adopted from previous recommendations from priming research (Bargh & Chartrand, 2000) and consisted of six questions about the priming procedure (see Appendix F). These questions investigated participant perspectives on: (1) the purpose of the experiment; (2) any curiosities during the experiment; (3) the relation of the cycling task and the computer task; (4) the effect of the computer task on the TTE; (5) the reason for the pattern that acted as the backward mask; (6) anything specific regarding the pattern.

4.3.6. Measurement of Effort

RPE was measured using the modified Borg CR10 scale. Low (0.5 = *very, very light*) and high (10 = *maximal*) anchors were established using standard procedures (Noble & Robertson, 1996). Furthermore, participants were informed that they were free to rate any number above 10 should the present state of effort have been perceived as higher than any previous maximal effort experienced. For the purposes of familiarisation, a Borg CR10 scale was provided to all participants after Visit 1. Standardized instructions regarding the CR10 scale were provided to all participants prior to each test with the emphasis that each rating should be based upon the effort required to pedal during the test as opposed to any limb discomfort that may be associated with the exercise. The Borg CR10 scale was automatically presented on the computer screen for every two minute measurement of RPE. Participants were requested to read out the value that corresponded to their present rating upon every presentation of the Borg scale. For each measurement, the scale remained on screen for 3850 ms and always replaced the black screen that appeared immediately after the backward mask.

4.3.7. Psychological Questionnaires

In order to evaluate differences in conscious affective state at baseline and throughout each visit, mood was assessed using two self-reported items of the positive (happy & joyful) and negative (sad & depressed) hedonic tone scales of the U-WIST mood adjective checklist (see Appendix G) developed and validated by Matthews, Jones, and Chaimberlain (1990). The four mood items were rated according to momentary affective state (*right now, I'm feeling*) on a 7-point likert type scale ranging from (1) *not at all*, to (7) *very much*. This scale has been used elsewhere in order to establish affective state during similar affect related subliminal priming interventions (Freydefont, Gendolla & Silvestrini, 2012; Silvestrini & Gendolla, 2011b) and was used in the present design to reflect this. In conforming to these previous interventions, a global measure of mood was established by summating the four mood items following each measurement.

Motivation was measured via the success motivation and intrinsic motivation scales developed and validated by Mathews, Campbell, and Falconer (2001). Each subscale consists of seven items responded to on a 5-point Likert type scale (0 = *not at all*, 1 = *a little*, 2 = *moderately*, 3 = *quite a bit*, 4 = *extremely*).

4.3.8. Statistical Analyses

Unless otherwise noted, data are shown as mean ± SD. After checking relevant parametric assumptions, paired sample *t*-tests were used to assess for group differences in

TTE, order effects of visit for TTE, mean cadence, pre-exercise mood and motivation, and various measures at exhaustion (RPE, heart rate, and blood lactate concentration). A 2 x 2 (Prime x Mood rating) fully repeated measures analysis of variance (ANOVA) was used to assess the effects of implicit affective priming on UWIST global mood ratings throughout each visit. A 2 x 5 (Prime x Time) fully repeated measures ANOVA was used to assess the effects of subliminal affective priming on RPE and heart rate at 0% (first minute), 25%, 50%, 75% and 100% (final full minute completed) of TTE. If assumptions of sphericity were violated the Greenhouse-Geisser correction was used while Tukeys HSD post hoc tests were calculated where appropriate. These variables were measured at the selected time-points to allow the comparison of temporal changes that may arise during the TTE test as a result of the affective prime. In order to obtain this iso-time data, the value of each parameter at 100% iso-time was established by identifying the shortest TTE accomplished by each individual over their two tests. The value for each variable attained during the final full minute of the shortest TTE test was then compared to the value attained during the equivalent minute of the longer TTE test. The minute identified as 100% iso-time was multiplied by 0.5 and rounded to the nearest time of rating where necessary to attain the value corresponding to 50% iso-time. To establish 25% iso-time values, the minute identified as 100% iso-time was multiplied by 0.25. To establish 75% iso-time the minute identified as 100% iso-time was multiplied by 0.25. Iso-time values for 0% were attained by comparing values for the first full minute of each TTE test. Standardized Cohen's *d* values (Cohen, 1988) are provided as an estimate of effect size. Thresholds for small, moderate, and large effect sizes were set at 0.2, 0.5, and 0.8, respectively (Cohen, 1988). Precision of the estimate is provided by ± 90% confidence intervals were relevant (Hopkins, Marshall, Batterham, & Hanin, 2009). This indicated the plausible range within which the true population effect for a measure resided (Cumming, 2014). Statistical significance was set at $p < .05$ (two-tailed) for all analyses and all data analysis was conducted using the statistical package for social sciences (SPSS version 16).

As null hypothesis significance testing is unable to convey the practical effect of an intervention, magnitude based inferences were also analysed (Batterham & Hopkins, 2006). This indicated the practical difference between affective priming conditions in the TTE test. The practical difference in TTE was established by subtracting the values from each visit to provide a difference between conditions. This same procedure was implemented at each measured iso-time point to assess the practical effect of subliminal affective priming on RPE and heart rate. Standardized values of Cohen's *d* (Cohen, 1988) are provided as an estimate of effect size throughout.

As recommended by Batterham and Hopkins (2006), to establish the practical significance of each measure, the smallest worthwhile change between priming conditions was based on a small Cohen's *d* effect size (>0.2). The statistical likelihood of meeting the smallest worthwhile change for each measure was calculated using a published spreadsheet (Batterham & Hopkins, 2006). Qualitative descriptors of the effect of the difference between affective priming conditions in relation to the smallest worthwhile change were assigned as follows: <1%; *almost certainly not*; <5% *very unlikely*; <25% *unlikely*; 25-75% *possible*; 75-95% *likely*; 95-99% *very likely*; >99% *almost certain*. Where the chance of benefit or harm were both >5%, the true effect was deemed *unclear* (Batterham & Hopkins, 2006).

4.4. Results

4.4.1. Effect of Implicit Affective Priming on Mood and Motivation

Baseline ratings on the U-WIST mood adjective checklist indicated that participants commenced the TTE test during each visit in comparable mood, $t(12) = 1.146$, $p = .27$.

Similarly, ratings for success motivation, $t(12) = 1.73$, $p = .11$, and intrinsic motivation, $t(12) = 1.95$, $p = .07$, were not statistically different between visits. This indicates that TTE was not influenced by pre-exercise mood, and that participants were motivated to perform the TTE test during both visits.

A 2 x 2 (Prime x Mood rating) fully repeated measures ANOVA did not detect any main effect between priming conditions for U-WIST mood adjective ratings, $F(1,12) = 3.37$, $p = .09$. A main effect for changes in mood rating throughout the visits was also not evident, $F(1,12) = 0.01$, $p = .76$. In addition no Prime x Mood rating interaction was apparent, $F(1,12) = 0.12$, $p = .73$. This implies that the implicit priming procedure did not elicit conscious alterations in mood immediately after the TTE test.

4.4.2. Effect of Implicit Affective Priming on TTE

As predicted, the implicit affective priming of emotional faces during endurance exercise had a significant effect on TTE, with participants cycling for 178 seconds longer when they were subliminally primed with happy faces in comparison to sad faces, $t(12) = -2.28$, $p = .04$, $d = 0.26$, 90% CI [38, 318] (see Figure 4.1). This equated to a *possible* practical effect of subliminal affective priming on TTE (Difference%: 70%). In conjunction with this, no order effect was present for TTE across visits, $t(12) = -0.65$, $p = .53$. As such the possibility that the present findings were influenced by a learning effect during the task can be ruled out.

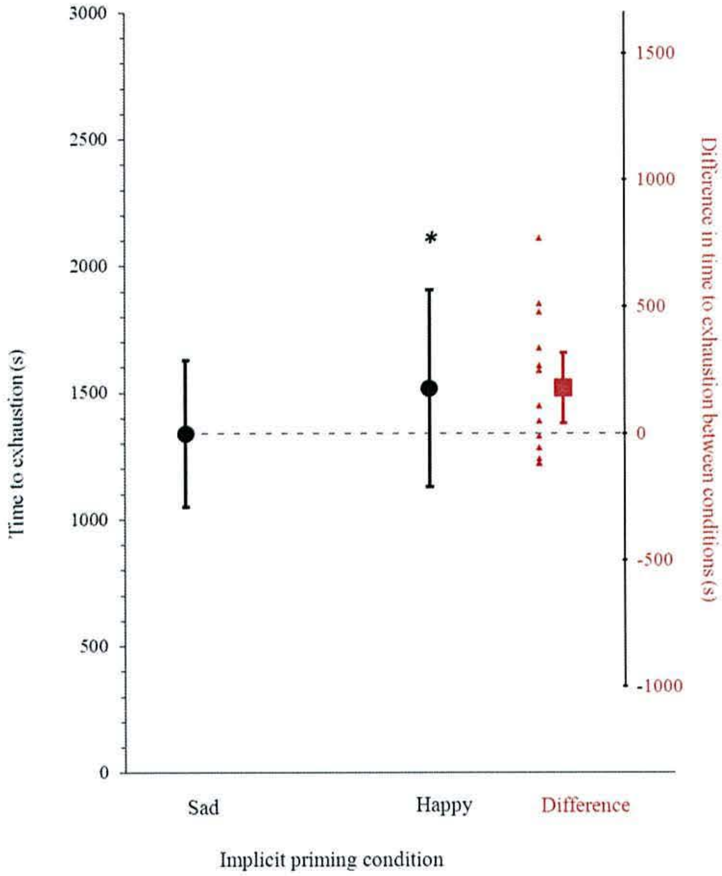

Figure 4.1. Mean (± 90% *CI*) cycling TTE during subliminal affective priming of sad and happy faces (black circles). Red square on floating secondary y-axis denotes difference in TTE between sad and happy affective priming conditions. Individual differences are represented by red triangles. * Indicates significant difference between conditions.

4.4.3. Effect of Implicit Affective Priming on Mean Cadence and also RPE, Heart rate, and Blood Lactate Concentration at Exhaustion

At exhaustion RPE was similar between priming conditions. This indicates that participants were willing to exert maximum effort during both conditions (see Table 4.1). Moreover, no differences were evident between conditions for heart rate at exhaustion, while blood lactate concentration at exhaustion was also similar. Mean cadence was however significantly different between conditions. Though this difference in means would be considered marginal

Table 4.1. Mean ± SD of physiological and perceptual measures at exhaustion.

	Sad	Happy	*p* value
Blood lactate (mmol · l)	7.13 ± 1.86	6.97 ± 2.51	.60
Heart Rate (beats · min^{-1})	180 ± 10	181 ± 10	.53
RPE (0-10+)	9.92 ± 0.28	9.96 ± 0.32	.33
Mean Cadence (rpm)	75.9 ± 4.5	77.9 ± 3.2	.01

Note. RPE = rating of perceived exertion; rpm = revolutions per minute

4.4.4. Effect of Implicit Affective Priming on Iso-time RPE and Heart Rate During the TTE Test

A significant main effect of RPE was present between the subliminal affective priming conditions. This corresponded to a lower RPE following the priming of happy faces, $F(1, 12) = 5.29, p = .04$. RPE significantly increased over iso-time measurements (see Figure 4.2), $F(2.13, 25.50) = 152.15, p = 0.001$. Despite this, no Prime x Iso-time interaction was detected for RPE during the TTE tests, $F(4, 48) = 1.43, p = .24$). The practical effect of implicit affective priming on RPE was found to be *unclear* at 0% and 100% iso-time and *likely* at 25%, 50%, and 75% iso-time (see Table 4.2).

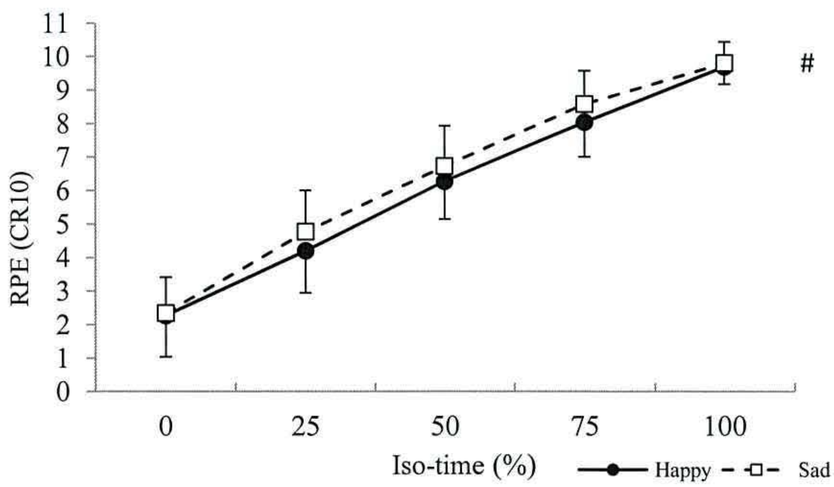

Figure 4.2. Mean (± *SD*) RPE at 0%, 25%, 50%, 75% and 100% iso-time for happy and sad implicit priming conditions. # Indicates significant difference between priming conditions

Table 4.2. Practical effect of subliminal affective priming on iso-time RPE during TTE test

	Mean ± SD Primed Happy Faces (Borg 0-10)	Mean ± SD Primed Sad Faces (Borg 0-10)	Difference Happy - Sad (Borg 0-10)	90% CI (Borg 0-10)	ES (*d*)	Magnitude (Difference%)	Practical Difference
RPE 0% Iso-time	2.27 ± 1.24	2.34 ± 1.07	-0.08	[-0.54, 0.38]	0.08	(29)	*Unclear*
RPE 25% Iso-time	4.19 ± 1.25	4.85 ± 0.76	-0.66	[-1.12, 0.19]	0.50	(92)	*Likely*
RPE 50% Iso-time	6.27 ± 1.13	6.73 ± 1.20	-0.46	[-0.90, -0.03]	0.40	(82)	*Likely*
RPE 75% Iso-time	8.08 ± 1.04	8.65 ± 1.07	-0.58	[-0.98, -0.18]	0.55	(92)	*Likely*
RPE 100% Iso-time	9.73 ± 0.52	9.81 ± 0.63	-0.08	[-0.41, 0.26]	0.13	(42)	*Unclear*

Note. RPE = perception of effort; 90% CI = 90% confidence intervals; ES (*d*) = Cohens *d* effect size

No main effect between priming conditions was evident for differences in heart rate at iso-time throughout the TTE tests, $F(1, 12) = 0.19, p = .67$. As would be expected, there was a main effect over time with heart rate at iso-time increasing progressively during the TTE tests, $F(1.22, 14.69) = 126.58, p = .001$. A Prime x Time interaction for heart rate was however not evident, $F(1.98, 23.74) = 1.08, p = .36$.

4.4.5. Manipulation Check.

During the funnelled debriefing procedure, the description given by all participants regarding their understanding of the experimental rationale conformed to the experimental rationale that they were provided with before the experiment. No participant was able to report anything strange that was related to the real experimental manipulation, no participant suggested that the computer screen affected what they did during the TTE test and no participant was able to decipher the real reason for the black and white patterned backward mask. Three participants mentioned a possible brief facial silhouette on one occasion within the flashed black and white pattern that acted as the backward mask. However when probed further, no participant was able to elaborate on the gender or facial expression of this silhouette. As no participant was suspicious of the study's true purpose at its culmination and no participant was aware of any facial expression within or prior to the flashed backward mask, this was considered to provide sufficient evidence of a successful experimental manipulation

4.5. Discussion

This study used subliminal affective facial cues to investigate the effect of implicitly manipulated affective cues on RPE and cycling TTE. As hypothesized, subliminally priming participants with happy faces whilst cycling at 65% PPO resulted in a significantly greater TTE in comparison to the priming of sad faces. Moreover, this difference in TTE between priming conditions was deemed to be *possibly* practical. In addition RPE was significantly lower during the TTE test when participants were subliminally primed with happy faces. This difference in RPE was also *likely* practical at 25, 50, and 75% iso-time. Consequently, the unique outcome of this investigation provides a novel perspective on the way that affective cues may influence physical endurance. These findings also generate a foundation for future research investigating the way that implicit cues might be implemented to elicit endurance performance enhancement.

To contextualize the current findings, a strong empirical foundation illustrating the relationship between affect and endurance performance has already been established (Beedie et al., 2000; Lane et al., 2011; LeUnes, 2000). Recent research has also hinted at the prospect that affect may indirectly influence endurance performance during experimental manipulations; although this could be considered equivocal. For instance, Terry, Karageorghis, Mecozzi, Saha, and D'Auria (2012) reported that motivational music increased treadmill TTE in conjunction with an elevated mood. On the other hand, Astorino, Cottrell, Lozano, Abutro-Pratt, and Duhon (2012) found that caffeine intake reduced feelings of pleasure but still improved 10km cycling time-trial performance in trained men. Nonetheless, these studies were not designed to exclusively manipulate affect. Moreover, music and caffeine are known to influence performance through psychological mechanisms other than affect; for example, motivation (Kaarageorghis & Preist, 2012; Meeusen, Roelands, & Spreit, 2013). As such, direct interpretations regarding the influence of manipulated affect and physical endurance cannot be obtained from these investigations. With this in mind, the present study provides the first experimental evidence that affective cues can influence physical endurance when they are directly manipulated. Even more importantly however, the current findings considerably extend this research area to show that physical endurance is altered by affective visual cues that occur outside of conscious awareness. This has previously unconsidered implications for endurance competitors who may be exposed to affective visual cues while taking part in training and endurance events.

The effects of non-conscious processes on human actions have been widely debated (e.g., Baumeister, Maisicampo, & Vohs, 2011). Even so, within the cognitive psychology literature, research has demonstrated the general influence exerted by implicit cues upon both cognitive and physical performance (Bargh et al, 2001; Pessiglione et al., 2007). For instance, subliminally delivered implicit reward priming has previously been shown to impact basic motor performance during handgrip related tasks (Aarts et al., 2008; Pessiglione et al., 2007). Moreover, subliminally presented affective cues have been shown to influence performance on cognitive tasks (Freydefont et al., 2012). Despite these findings, comparative research investigating the manipulation of implicit cues during dynamic endurance performance is limited to two studies (i.e., Banting et al., 2011; Hodgins et al., 2006). Each of these reported that motivationally orientated implicit primes enhanced their respective measures of endurance performance. This therefore bolsters the present findings. It should be cautioned however that the implicit primes in those studies were implemented supraliminally (i.e., above the conscious perception threshold). Consequently, the formation of conscious intentions following prime exposure may not have been fully eliminated (Custers & Aarts, 2010). Moreover, neither of these studies provided any insight into the effects of implicit affective cues. As such, the current investigation bolsters this previous research in two ways; firstly it has addressed a gap in the literature to show that the implicit regulation of physical endurance extends beyond motivational elements to also encapsulate affective cues; secondly it has addressed this gap by utilizing a less consciously susceptible aspect of implicit priming, notably in the form of subliminal cues. Collectively this supports the general concept that non-conscious processes can effect human behaviour, specifically in the context of dynamic whole body endurance exercise.

Alongside the performance related effects of affective cues, cognitive effort is also altered when affective states are manipulated (Freydefont et al., 2012). However, similar to dynamic endurance performance, the effect of such cues upon physical effort perception remained unexplored. Gendolla (2000) has previously suggested that affective states influence the appraisal of task demand and the subjective experience of task related effort. For example, positive moods have been found to reduce appraisals of task demand and experienced effort whereas negative moods have the opposite effect (Gendolla & Krüsken, 2001). This has also been demonstrated implicitly with subliminally primed happy faces presented during cognitive activity prompting a greater willingness for effort in comparison to sad faces (Silvestrini & Gendolla, 2011b). This corresponds to the predictions made by motivational intensity theory (Brehm & Self, 1989). Hence, lower appraisals of task demand coincide with a reduced experience of effort during objectively easy tasks, whereas effort is more willingly tolerated as tasks become more difficult. Conversely, increased appraisals of task demand coincide with an elevated experience of effort during objectively easy tasks, whereas effort is more readily withheld as task difficulty increases (Gendolla & Krüsken, 2001).

The psychobiological model of endurance performance (Marcora et al., 2008), based on motivational intensity theory (Brehm & Self, 1989) predicts that any physiological or psychological factor affecting RPE and/or potential motivation will affect endurance performance (Marcora et al., 2008). This model has already been shown to account for performance differences stemming from factors as diverse as eccentric muscle damage (Marcora et al., 2008), cognitive fatigue (Marcora et al., 2009), and motivational self-talk (Blanchfield, Hardy, de Morree, Staiano, & Marcora, 2013) and is supported by a variety of other interventions involving psychostimulant manipulation (Sgherza et al., 2002; Jacobs & Bell, 2004), sleep deprivation (Martin, 1981), inspiratory muscle fatigue (Gething, Williams, & Davies, 2004), nutritional ingestion (Blackhouse, Bishop, Biddle, & Williams, 2005), and aerobic training (Ekblom & Goldbarg, 1971). In the present study, RPE was significantly lower during the subliminal priming of happy faces, in comparison to the subliminal priming of sad faces. The effort related effects of non-conscious affective cues therefore seemingly extend beyond cognitive tasks and influence physical endurance tasks in the same manner. This provides support for the psychobiological model of endurance performance and warrants further investigation into the effects of various implicit cues upon RPE.

In further support of the influence of implicit affective cues on RPE in the present study, the difference in TTE cannot be attributed to discrepancies in pre-exercise mood or motivation because these were similar between implicit priming conditions. Furthermore basic physiological factors are unlikely to have caused any changes in TTE between subliminal priming conditions because no significant differences were evident in heart rate or post-exercise lactate. Mean cadence was however different between conditions. While this could be used to infer differences in motor unit recruitment or cycling efficiency (Dantas et al, 2009), the marginal mean difference in mean cadence in the present study is unlikely to have contributed to changes in physical endurance (Dantas et al., 2009; Sarre, Lepers, Maffiuletti, Millet, & Martin 2003).

Although more complex physiological mechanisms cannot be ruled out, one potential explanation for the difference in TTE between priming conditions is associated with non-consciously activated mental representations of emotion concepts (Niedenthal, Winkielman, Mondillon, & Vermuelen, 2009). These emotion concepts have been viewed as an individual schema of memories, motivations and behaviours that are associated with a specific emotion (Lang, Bradley, & Cuthbert, 1998). Moreover, when these emotion concepts are activated by a specific affective cue, they are suggested to make the behavioural response that is associated with the cue more likely (Silvestrini & Gendolla, 2011b; Zemack-Rugar, Bettman, & Fitzsimons, 2007). In the case of the current study, implicit priming with happiness and sadness cues may have respectively activated the concepts of ease and difficulty that have been associated with these emotions (Gendolla, 2012; Silvestrini & Gendolla, 2011b). A scenario in which the mental representation of ease was activated for example would permit a comparative reduction in RPE and allow individuals to cycle for longer before they reached the point at which a further increase in RPE seemed impossible. In individuals who were willing to exercise to maximum, this would delay voluntarily task disengagement.

As an aside, positive and negative affective cues have also been linked to approach and avoidance motivation (Winkielman & Nowak, 2005). For instance it has been found that positively valenced stimuli evoke automatic approach tendencies whereas negatively valenced stimuli have the opposite effect (Chen & Bargh, 1999; Krieglmeyer, Deutsch, De Houwer, & De Raedt, 2010). Because affective cues have previously been shown to influence full body approach and avoidance behaviour (Mayan & Meiran, 2011), it is possible that implicitly activated happiness provoked an approach motivated orientation during the TTE test, hence participants cycled for longer before voluntary task termination. Conversely sadness cues may have initiated an avoidance motivated response; causing participants to terminate the TTE test sooner than usual. It should be cautioned however that this interpretation is somewhat ambivalent owing to recent research by Vrijsen, van Oostrom, Speckens, Becker, and Rinck (2013) who do not corroborate that happy and sad faces respectively elicit approach and avoidance in healthy individuals. Moreover this study did not measure approach and avoidance motivation so this cannot be verified.

Along with the similar pre-exercise mood ratings, conscious appraisals of mood did not change from pre to post-exercise and were not different between affective priming conditions. These similarities in conscious mood ratings might initially imply that the subliminal manipulation of affect in the present study was not effective. However, the present finding is consistent with other studies that have utilized implicit affective priming (Silvestrini & Gendolla, 2011; Winkielman et al., 2005; Zemack-Rugar et al., 2007). In these studies it has been suggested that not only are implicit affective cues able to modify affective states, but that the affective state itself is also not consciously experienced. This phenomenon has again been attributed to the non-conscious activation of mental representations such that behavioural alterations that are aligned with changes in affect occur despite the inability of participants to consciously report a change in affective state (Zemack-Rugar et al., 2007). As conscious affect was not measured during the TTE test while the implicit priming procedure took place however, this is currently a hypothetical consideration. Nonetheless, the concept that physical endurance can be altered even when a changes in affective state is not consciously observed does impart an intriguing direction for future research.

It is important to recognise some potential limitations relating to the present study. For instance, as already alluded to, mood was only consciously measured before and after the TTE test. Consequently this study is not able to demonstrate that mood was consciously altered during the test as a result of the affective priming manipulation. However, it was decided to omit the conscious measurement of mood during the TTE tests because of the possible confounds associated with this. For example, it was reasoned that exposing participants to a subjective rating of mood during the TTE test may inadvertently influence the subjective rating of RPE. It was also imperative to minimize distractions to ensure that attention remained directed at the computer screen on which the subliminal primes were delivered. Furthermore, because heart rate, lactate, and pre-exercise mood and motivation were not significantly different between priming conditions; it is difficult to establish any factor other than the manipulation that could have altered TTE. Moreover, no order effect was detected between conditions and data from the post-study funnelled debriefing procedure provided support for the subliminal priming manipulation. That said, due to the crossover design of the investigation a forced recognition check was not carried out at the culmination of the study. Again however this was due to methodological design. Primarily because the study consisted of a crossover design, it was impossible to include a forced recognition check at the end of the first priming visit. As such, a forced recognition check only after the second priming visit could have introduced recall bias because participants would have been required to recall facial expressions not only for the task that they had just completed but also for the one from the previous visit. Finally, because a control group was not utilized in the present study it is not possible to establish whether the difference in TTE resulted exclusively from an increase in physical endurance following exposure to the happy primes or a decrease in physical endurance following exposure to the sad primes, or a combination of both.

Notwithstanding the methodological considerations, this exploratory study was designed to assess the plausibility of implicit priming as a basis for future performance enhancing investigations. For instance, it is important now to establish whether implicit attentional biases towards certain visual affective cues may differ between particular populations (e.g., recreational individuals vs. elite competitors), or individuals of different capabilities within a defined population. Specifically, in much the same way that smokers display implicit attentional biases towards smoking cues (Littel & Franken, 2011), certain individuals may be more susceptible to implicit attentional biases that relate to a specific affective state during endurance exercise. Similarly it would be useful to determine whether factors such as exercise intensity and effort perception moderate implicit attentional biases to visual affective cues. Moreover, interventions designed to more permanently alter how individuals respond to implicitly affective cues, for instance their implicit attentional biases to various affective cues, could be a valuable addition to any training regimen. It is also possible that these future research suggestions are also extendable to sedentary individuals in whom psychological barriers to exercise may presently exist.

More obvious directions for future research include further investigation into the effects of these visual affective cues on RPE. The addition of a control group to the present design would also help to establish which affective prime (i.e., happy or sad) was responsible for the present difference in TTE. Such an approach might provide robust support for the use implicit affective cues as a direct strategy for endurance performance enhancement. Furthermore, the measurement of conscious affective state during exercise would permit a more definitive appraisal of whether the affective state itself also occurred outside of conscious awareness. Finally, the impact of alternative visual implicit affective cues that are more directly relevant to endurance exercise such as the face of effort (de Morree & Marcora, 2012), or facial cues relating to fatigue and arousal, and also alternative cues such as body posture, may provide further invaluable insights into some of the factors that non-consciously influence endurance performance, as would implicit activations of other sensory systems such as the olfactory and auditory systems.

In conclusion, the findings of the present study show that implicit exposure to happy and sad affective cues can influence RPE and physical endurance. These findings corroborate the suggestion that the limits to physical endurance are regulated by psychobiological factors. Together, this supports the basis of psychobiological model of endurance performance and the suggestion that any physiological or psychological factor affecting RPE and/or potential motivation will affect endurance performance (Marcora et al., 2008). The present research also has considerable implications for endurance competitors who may be subjected to implicit affective facial cues during training and competition. Accordingly it provides a pertinent basis for further investigation into the role played by implicit cues during endurance performance, particularly regarding strategies for endurance performance enhancement.

CHAPTER 5

The Effect of Subliminally Primed Action and Inaction Words on RPE and Time to Exhaustion: A Randomization Tests Approach

5.1. Abstract

Purpose: Primed action and inaction words have been shown to influence motor activity during basic physical tasks. When primed subliminally, action and inaction words have also been shown to alter cognitive effort. Collectively this infers that action and inaction words may alter effort and endurance during whole body, dynamic physical tasks. Presently however, this inference has not been experimentally tested. Using a single subject approach, this study therefore investigated the influence of action and inaction words on perception of effort (RPE) and physical endurance. **Method**: One male participant (age 22 years; peak power output 287 W; $\dot{V}O_{2max}$ 58.3 ml·kg^{-1}·min^{-1}) performed 12 constant-intensity (65% peak power output) cycling time to exhaustion tests (TTE) while being subliminally primed with action or inaction related words in a block randomized, counterbalanced, crossover design. **Results**: Randomization tests revealed that TTE was significantly (~16.8%) greater when the participant was subliminally primed with action words versus inaction words (2557 ± 606 s vs. 2158 ± 706 s, p = .04). RPE was also significantly lower during action word priming at minutes 10, 11, 13, 14, and 15. **Conclusion**: This study is the first to demonstrate that subliminally primed action and inaction words can alter physical endurance and RPE. Simultaneously the study exemplifies the utility of randomization tests as a robust statistical approach to single subject research. These findings generate a foundation for RPE based performance enhancing investigations using action words and demonstrate an effective methodological approach to single subject research for sport and exercise scientists.

Descriptors: Subliminal, endurance, action words, RPE, psychobiological model.

5.2. Introduction

Words denoting action related concepts have been shown to activate the motor areas of the brain (Hauk, Johnsrude, & Pulvermüller, 2004). This suggests that action words prime the organism for motor related acts (Pulvermüller, 2005). Recently, in comparison to primed inaction words, primed action words have been shown to prompt greater activity during basic physical tasks such as drawing on a piece of paper, and chewing (Albarracin et al., 2008). In addition, this priming effect appears to be general and non-specific such that the priming of the same general action and inaction words influences motor behaviour across a variety of tasks (Albarracin, Hepler, & Tannenbaum, 2011). This priming effect of general action and inaction words on behaviour has also been expanded by Gendolla and Silvestrini (2010) to investigate their influence on effort related processes. Specifically, subliminally primed action words enhanced participant willingness to exert effort during the performance of a cognitive task whereas implicitly primed inaction words led to premature effort withdrawal during the same task.

Effort related processes are an important component of physical endurance tasks (Jacobs & Bell, 2004; Marcora, Staiano, & Manning, 2009); not least because it has been proposed that the limit to physical endurance is determined by effort based voluntary decision making, as opposed to physiological exhaustion (Marcora, 2008). Accordingly, perception of effort (RPE) is suggested to act as a major determinant of endurance performance (Marcora, 2008). In this regard, the psychobiological model of endurance performance (Marcora, 2008), based on motivational intensity theory (Brehm & Self, 1989) proposes that an individual will voluntarily terminate endurance exercise either when the effort required by the task exceeds the maximum amount of effort that they are willing to experience in order to succeed in the task (i.e. potential motivation) or when continuation in the task is perceived to be impossible. This contention is supported by a number of psychobiological interventions including the implementation of cognitive fatigue (Marcora et al., 2009), the use motivational self-talk (Blanchfield, Hardy, de Morree, Staiano, & Marcora, 2013), and the induction of pre-exercise muscle damage (Marcora, Bosio, & de Morree, 2008). As such, the psychobiological model predicts that any physiological or psychological factor effecting RPE should therefore affect the point at which an individual voluntarily terminates endurance exercise.

General action and inaction are suggested to represent motivational end states that regulate the corresponding pursuit of high effort and low effort (Albarracin et al., 2011). This infers that priming action and inaction words may facilitate effort induced differences in the limits to physical endurance such that the increased motor activity accompanying with primed action words would be associated with greater physical endurance compared to primed inaction words. According to the psychobiological model of endurance performance, such a difference in physical endurance during action and inaction word priming would be driven by differences in RPE. This is plausible given the previous findings by Albarracin et al. (2008) and Gendolla and Silvestrini (2010). Consequently, establishing whether primed action and inaction words are able to alter RPE and the limits to physical endurance may therefore construct a foundation for performance based interventions.

As is the case with all of the aforementioned research, most investigations in sport and exercise science are structured around group based experimental designs. When adequately implemented, this approach allows statistical inferences about an effect to be applied to a specific population. To date, this type of approach has facilitated a detailed understanding of important performance related concepts such as effective training protocols (Midgley, McNaughton, & Wilkinson, 2006), nutritional strategies (Burke, Hawley, Wong, & Jeukendrup, 2011), recovery interventions (Reilly & Ekblom, 2005), and fatigue (Ament & Verkerke, 2009). Although this approach possesses many strengths, it is also susceptible to some weaknesses; a pertinent one being that experimental effects are rarely evident for all individuals within a sample. This is illustrated by the fact that for a treatment obtaining a moderate Cohen's *d* effect size of 0.5, 31% of the treatment group will still fall at or below the mean value of the control group (Cumming, 2012). Conversely, treatment effects found to be non-significant may mask the positive effects of an intervention on specific individuals. Consequently, using group based experimental designs to generalise treatment effects to specific individuals within a population can be problematic. In order to investigate individual treatment effects it is therefore necessary to adopt an alternative methodological approach.

Single subject designs offer an alternative perspective on the efficacy of an intervention by focusing on individual treatment effects. This approach can therefore be implemented to clarify the effects of a treatment on an individual basis. This is advantageous in scenarios involving unique populations or where sufficient sample sizes and optimal experimental control are difficult to acquire; for instance, elite athletes. These merits of single subject designs in sport and exercise science have been acknowledged for over a decade (Kingusa, Cerin, & Hooper, 2004). Nonetheless, the use of single subject designs remains surprisingly scant (Barker, Mellalieu, McCarthy, Jones, & Moran, 2013). It is suggested that this is because many investigators still question the credibility of single subject designs in scientific research (McDougall, 2013). This suspicion is possibly due to the predominant use of case studies, quasi-experimental designs, and subjective interpretation; hence the lack of experimental and statistical rigor that is thought to accompany many group based designs. This is illustrated by the frequent reliance on subjective visual analysis to assess data (Lambert, Moore, & Dixon, 1999; Ward & Carnes, 2002). With this in mind, more single subject interventions would benefit from the use of well controlled, randomized experimental designs that are analysed using objective statistical approaches. Such an approach can be achieved through the implementation of randomization tests (Dugard, File, & Todman, 2012). In randomization tests an intervention effect is assessed by randomly assigning a participant to treatment conditions that are implemented multiple times across a number of test visits (Rvachew, 1988). Nonetheless, although applicable to various scenarios in sport and exercise science, this method of research design and analysis appears to be underused with only one intervention seemingly having implemented this approach to date (Kinugasa, Miyanaga, Shimojo, & Nishijima, 2002).

The aims of this investigation were to assess the effect of primed action and inaction words on TTE and RPE. To follow on from the established effects of subliminal affective priming on RPE and physical endurance in Chapter 4, the primes were delivered subliminally. Importantly, this subliminal approach to action and inaction word priming has been shown to be an effective way of manipulating effort in previous studies (Gendolla & Silvestrini, 2010; 2013). In contrast to the group based design in Chapter 3 however, the current priming intervention was carried out using a single subject design. This was to exhibit the utility of randomization tests for single subject analysis in sport and exercise science. It was hypothesised that TTE would be greater and RPE would be reduced when the participant was subliminally primed with action words in comparison to inaction words.

5.3. Method

5.3.1. Participant Characteristics and Ethics

One male participant [age 22 years, peak power output 287 W, maximum oxygen uptake ($\dot{V}O_{2max}$) 58.3 $ml \cdot kg^{-1} \cdot min^{-1}$] volunteered to take part in the study. The participant was actively engaged in a form of individual endurance exercise on at least two occasions per week. The participant received £150 (approximately \$250 / €180) for their involvement in the study. The study was approved by the ethics committee of the School of Sport, Health and Exercise Sciences (SSHES), Bangor University. Prior to taking part the participant completed an informed consent form along with a standard medical questionnaire to confirm his present state of health. The participant was provided with a detailed overview of all procedures and requirements of the study before its commencement and was informed that the study was a reliability study that was designed to test the ability of a wireless electroencephalography unit to accurately detect the cerebral response to unexpected computer stimuli. Consequently, the participant was naive to the true aims and hypotheses until the cessation of the study, at which point he was debriefed about its genuine rationale.

5.3.2. Study Design

The study consisted of a single blind, blocked randomization test design in which the participant visited the laboratory on 14 occasions. Visits 1 and 2 involved the maximal incremental test and a familiarisation session respectively and visits 3 to 14 were comprised of the 12 experimental visits (see Procedures). These 12 experimental visits encompassed a crossover design in which the participant was randomly allocated to 6 visits for each of the two experimental treatment conditions (subliminally primed action vs. inaction words). The order of treatment visits was randomized in three blocks of four. These were categorized in sequence as Blocks 1, 2, and 3. Accordingly, within each block the individual was randomly allocated to two visits for each treatment. This blocked procedure was performed to mitigate learning effects throughout the intervention as well as the possibility that consecutive TTE tests may elicit a progressive training effect. The blocks of randomized visits were merged in numerical sequence to create one complete experimental arrangement of treatments across the 12 visits *(Block 1: action, inaction, inaction, action; Block 2: inaction, inaction, action, action; Block 3: inaction, action, inaction, action).*

5.3.3. Procedures

All trials were conducted at the same location, at a similar time of day, on the same electromagnetically braked cycle ergometer (Excalibur Sport, Lode, Groningen, Netherlands). Saddle and handlebar specifications on the cycle ergometer were adjusted on the first visit to suit participant preference. These specifications were then maintained for every visit. During Visit 1, the participant completed the informed consent questionnaire and a checklist to ensure compliance with pre-task instructions; anthropometric measurements were then recorded. After this, an incremental ramp test was carried out on a cycle ergometer to establish peak power output (PPO) and $\dot{V}O_{2max}$. The incremental ramp test began with a two minute rest after which power output was increased by 25W every minute until volitional exhaustion. Exhaustion was operationally defined as the voluntary cessation of the task by the participant or the inability to maintain a pedal frequency of 60 revolutions per minute (RPM) despite strong verbal encouragement. For the test, the ergometer was set in hyperbolic mode, which allows the power output to be set independently of pedal frequency over a range of 30-120 RPM, and the participant was instructed to remain in the saddle at all times. $\dot{V}O_{2max}$ was measured breath by breath via a computerized metabolic gas analysis system (Metalyzer 3B, Cortex Biophysik, Leipzig, Germany) connected to an oro-(mouth) mask (7600 series, Hans Rudolph, Kansas City, MO). The device was calibrated before each test using a known concentration of gases and a 3.0 litre calibration syringe (Series 5530, Hans Rudolph). Heart rate was recorded 15 seconds from the end of the two minute rest using wireless chest strap radio telemetry (S610, Polar Electro, Kempele, Finland) and was measured every minute during the test thereafter. RPE was also recorded every minute during the test according to standard instructions using the 11 point Borg CR10 scale (Borg, 1998).

Visit 2 consisted of a familiarisation session in which the participant completed all questionnaires (see Psychological questionnaires) and the TTE test that was to be used during the 12 experimental visits. Upon arrival for Visit 3 the participant completed mood and motivation questionnaires (see Psychological questionnaires), this was followed by the cycling TTE test. For the TTE test, the participant was positioned on the cycle ergometer (set to hyperbolic mode) and instructed to remain in the saddle at all times. The test began with a three minute warm up at 30% of the participants' PPO. After three minutes the power output was automatically increased to a power output corresponding to 65% PPO. The test remained at this constant intensity of 65% PPO until its cessation. Pedal cadence was freely chosen between 60 – 100 RPM and was recorded every minute during the test, as was heart rate (see Additional physiological measures). RPE (see Measurement of effort) was recorded using the 11 point Borg CR10 at one minute intervals during the task. TTE was defined as the cycling time achieved from the end of the 3 minute warm up to the moment at which the participant either voluntarily terminated the task or pedal cadence had fallen below 60 RPM for five consecutive seconds. No verbal encouragement was provided at any point during the TTE test to eliminate the superimposition of any extraneous verbal statements. To avoid bias, the experimenter stood behind participants at all times (Tassinary, Cacioppo, & Vanman, 2007). Exactly three minutes after the cessation of the TTE test the participant provided an earlobe sample of whole fresh blood for lactate analysis (see Additional physiological measures).

Throughout the TTE test the participant was exposed to the computerized scanning visual vigilance task on a screen directly ahead (see Computerized scanning visual vigilance task). The task commenced at the onset of the TTE test, following the three minute warm up, and stopped when the TTE test was voluntarily terminated. Corresponding to the blocked randomization tests allocation, either the action or inaction word primes were delivered within the scanning visual vigilance task for the duration of the TTE test (see Subliminal priming procedure). The computer screen was placed at eye level 60 cm away from the participant during every TTE test. The participant also wore a wireless electroencephalography unit throughout every TTE test. This procedure was however used as a sham to conceal the true purpose of the study. As such the unit was not active during any of the visits.

All procedures for the remaining 11 experimental visits were identical to Visit 3, other than the allocated word priming treatment during each respective visit. At the end of Visit 14 the participant underwent a standardized funnelled debriefing procedure (Bargh & Chartrand, 2000) to probe for interpretation of the experimental hypothesis and awareness of the subliminal primes. The participant also underwent a prime awareness task in which he was required to identify any word primes that were recognisable from the experimental visits. After being fully debriefed the participant was thanked and then received his payment.

Visits 1, 2, and 3 were separated by a minimum of 7 days each, while all visits between Visits 3 and 14 were separated by a minimum of 6 days and a maximum of 14 days. Throughout the intervention, the individual was instructed to maintain his normal exercise programme. As instructed prior to each visit, the participant preserved similar dietary patterns during the preceding 24 hours while consuming an amount of water equivalent to least 35 $ml \cdot kg^{-1}$ body weight and attaining at least 7 hours of sleep the night before. The participant also avoided any heavy exercise in the 24 hours prior to testing and refrained from the consumption of caffeine and nicotine in the 3 hour period leading up to each test. Finally, the participant voided before each test and performed during all visits in similar clothing. The participant remained unaware of his TTE value for the familiarization visit and for every subsequent visit until the final debriefing procedure.

5.3.4. Computerized Scanning Visual Vigilance Task

The computerized scanning visual vigilance task (Lieberman, Coffey, & Kobrick, 1998) was used to provide an effective method of delivery for the computerized subliminal action and inaction word primes during the TTE test. As cognitive effort has been shown to affect TTE and RPE (Marcora et al., 2009), this task was selected to minimize the amount of cognitive activity that was imposed upon the participant during the TTE test. The participant was therefore requested to focus on the computer screen at all times and informed that a green circle of 3 cm diameter would appear at a random location on the screen. The time that elapsed between each individual appearance of the circle was no shorter than 45 seconds, and no longer than 90 seconds. The participant was informed that when the circle appeared he was not to respond but should continue cycling whilst maintaining focus upon the screen. Each 3 cm green circle appeared at an identical time and screen location during all visits.

5.3.5. Subliminal Priming Procedure

In conjunction with visit allocation, action or inaction words were subliminally primed within the computerized scanning visual vigilance task for the duration of each TTE test. One prime sequence was presented serially every 4996 ms. Each prime sequence consisted of a white fixation cross that was displayed on a black background in the centre of the screen (1000 ms). This was instantly followed by a word prime (16 ms) that was backward masked by a random letter sequence (130 ms). This random letter sequence always consisted of the letters MZKGWB and appeared after every word prime. Following the backward mask, the screen either remained black (3850 ms) or alternatively a green circle of 3 cm diameter appeared against the black background in a random location on the screen (3850 ms). The next word prime sequence was commenced immediately after. To prevent habituation to the subliminal word primes, two thirds of the primes consisted of non-word primes with the remaining one third consisting of the word primes (Silvestrini & Gendolla, 2011). To ensure that exposure to the subliminal word primes occurred throughout each TTE test, two word primes were randomly presented within each six prime sequence. The remaining four primes within each six prime sequence therefore consisted of the non-word primes. The word primes were obtained from the empirically derived Computerized Edinburgh Associative Thesaurus (Kiss, Armstrong, Milroy & Piper, 1973). The selected action primes consisted of the words *ACTION*, *GO*, *LIVELY* and *ENERGY*. The inaction primes consisted of the words *STOP*, *TOIL*, *SLEEP*, and *TIRED*. The non-word primes were created by re-arranging the letter order of the action and inaction words. The word primes, non-word primes, and the backward mask were all presented in white capital letters of size 125 calibri font in the centre of the screen and against a black background. The priming programme was generated in E-prime software (E-Prime, Psychology Software Tools, Pittsburgh, PA) and the primes were presented on a 19` computer monitor with an aspect ratio of 16:9, a refresh rate of 60 Hz and a 1280 x 720 pixel array.

5.3.6. Funnelled Debriefing and Forced Recognition Task

The funnelled debriefing procedure was administered as a manipulation check to ensure that the participant was not consciously aware of the action or inaction word primes during the subliminal priming procedure. This method was adopted from previous recommendations in priming research (Bargh & Chartrand, 2000) and consisted of six questions about the priming procedure (see Appendix H). These questions investigated participant perspectives on: (1) the purpose of the experiment; (2) any curiosities during the experiment; (3) the relation of the TTE test and the computer task; (4) the effect of the computer task on the TTE test; (5) the reason for the random letter string that acted as the backward mask; and (6) anything specific regarding the letters. For the forced recognition task, the participant was presented with every action and inaction word that was used during the investigation and also the rearranged non-words. The participant was then instructed to indicate whether he recognised each word from the task and all responses were recorded.

5.3.7. Measurement of Effort

RPE was measured using the modified Borg CR10 scale. Low (0.5 = *very, very light*) and high (10 = *maximal*) anchors were established using standard procedures (Noble & Robertson, 1996). Furthermore, the participant was informed that he was free to rate any number above 10 should the present state of effort have been perceived as higher than any previous maximal effort experienced. For the purposes of familiarisation, a Borg CR10 scale was provided to the participant after Visit 1. Standardized instructions regarding the CR10 scale were provided to the participant prior to each test with the emphasis that each rating should be based upon the effort required to pedal during the task as opposed to any limb discomfort that may be associated with the exercise. The Borg CR10 scale was presented on the computer screen every minute for the measurement of RPE. The participant was requested to read out the value that corresponded to his present rating upon every presentation of the Borg scale. For each measurement, the scale remained on screen for 3850 ms and always replaced the black screen that appeared immediately after the backward mask.

5.3.8. Monitoring of Physical Training Load

The participant was instructed to maintain a steady physical training load during the intervention. This was to eliminate the impact of physical training on performance in the TTE tests. Accordingly, a training diary was supplied to monitor physical training load via the session RPE method (Foster et al., 2001). For this, the participant was instructed to record the duration of each training session and a single global RPE for that session using the Borg CR10 scale. The global RPE rating for each session was to be recorded 30 minutes after the session had ended. A training impulse value for each session was then obtained by multiplying the global RPE of that session by its corresponding duration.

5.3.9. Psychological Questionnaires

The Brunel mood scale (BRUMS) was used to assess pre-exercise mood. This measure of mood has been validated for use with adult populations (Terry, Lane, & Fogarty, 2003). The measure is comprised of six subscales (anger, confusion, depression, fatigue, tension, & vigour) with four items per subscale. Items were answered on a 5-point Likert type scale (0 = *not at all*, 1 = *a little*, 2 = *moderately*, 3 = *quite a bit*, 4 = *extremely*).

Motivation was measured via the success and intrinsic motivation scales developed and validated by Mathews, Campbell, and Falconer (2001). Each scale consists of seven items on a 5-point Likert type scale with identical anchors to those described above.

5.3.10. Statistical Analyses

Unless otherwise noted, data are shown as mean ± SD. Randomization tests (Dugard et al., 2012) were used to assess for mean differences between treatments (action vs. inaction words) in TTE, end exercise heart rate, lactate, final RPE, all BRUMS subscales, and success and intrinsic motivation. Randomization tests were also used to assess differences between conditions for RPE and heart rate at every minute throughout the TTE tests until the 15th minute. Fifteen minutes was selected as this represented the final full minute of the shortest TTE over the 12 Visits.

For each randomization test, in order to test for statistical significance, mean values for each treatment condition were first calculated. The difference between these means was then obtained. These values provided the true experimental difference between treatments for each dependent variable. The randomized order of experimental treatments across the 12 visits represented one of many possible ways in which the treatment visits could have been arranged. Using a pre-designed macro (Dugard et al., 2012) the raw data from the 12 experimental treatment visits was randomly rearranged 2000 times to coincide with alternative visits in the original treatment allocation. For each of these 2000 rearrangements, only the raw data from treatment conditions was randomly rearranged with the allocated treatment order of the respective 12 experimental visits remaining the same. Specifically, this meant that the raw data for each visit was randomly swopped between the allocated treatment visits two thousand times. Due to the present design, this procedure was performed only on a within block basis. Hence for example, a raw data value from Block 1 could not be rearranged to a visit in Blocks 2 or 3. Rearranging the raw data in proximity to the assigned visits in this manner permitted the calculation of a hypothetical mean difference between treatment conditions for each of the 2000 treatment rearrangements. In order of magnitude from high to low, the true mean difference was then ranked amongst the 2000 hypothetical mean differences that were obtained from the treatment rearrangements. Statistical significance was obtained if the mean difference for the experimental data was greater than 95% of the hypothetical mean differences acquired from the 2000 treatment rearrangements. Statistical significance was set at $p < 0.05$ (one-tailed) for TTE and RPE and $p < 0.05$ (two-tailed) for all other analyses. All data analysis was conducted using Microsoft Excel 2010.

5.4. Results

5.4.1. Funnelled Debriefing, Prime Recognition Task, and Training Load

A qualitative evaluation of the funnelled debriefing procedure indicated that the participant believed the cover rationale for the investigation to be genuine throughout. The participant also did not detect any subliminally primed action and inaction words during the 12 visits. The participant therefore remained naive to the true experimental hypothesis during the investigation. In addition, the participant was unable to identify any subliminally primed words or rearranged words during a forced recognition task at the end of the study. Together these checks demonstrate that the experimental manipulation was rigorous throughout. The participant however did not record a global RPE value for any training sessions. Weekly training load could therefore not be established.

5.4.2. Effect of Subliminal Action and Inaction Word Priming on Mood and Motivation

A randomization test for each BRUMS subscale revealed no significant differences between conditions (see Table 5.1). This indicates that the participant began all TTE tests for each condition in a similar mood. Similarly, no significant differences were evident between conditions for ratings of success or intrinsic motivation. Similar to mood, the participant therefore commenced all TTE tests between each condition in an equally motivated state.

Table 5.1. Mean ± SD participant rating for all BRUMS subscales and success and intrinsic motivation prior to TTE tests

	BRUMS Subscales						Motivation	
	Anger	Confusion	Depression	Fatigue	Tension	Vigour	Success	Intrinsic
Action	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	2.83 ± 0.75	14.33 ± 1.97	28.00 ± 0.00	28.00 ± 0.00
Inaction	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	4.17 ± 0.75	14.83 ± 0.98	27.67 ± 0.52	28.00 ± 0.00
p value	= .99	= .99	= .99	= .99	= .90	= .92	= .33	= .99

Note. Pre = pre-intervention visit; Post = post-intervention visit; Con = control group; ST = Self-talk group.

5.4.3. Effect of Subliminal Action and Inaction Word Priming on TTE

When primed with action words, TTE was 2577 ± 606 seconds, compared to a TTE of 2178 ± 706 seconds following inaction word priming (see Table 5.2). This difference of 399 seconds between conditions was ranked within the top 3.6% of means that were obtained from the 2000 alternative random treatment arrangements. TTE was therefore significantly greater following the subliminal priming of action words versus inaction words ($p = .04$).

Table 5.2. Individual data by block, visit order, and assigned treatment condition for TTE, end heart rate, end lactate, mean cadence, and end RPE

Block	Visit	Condition	TTE (s)	HR_{end}	Lactate (mmol·l)	Cadence (RPM)	RPE_{end}
1	1	A	1772	140	2.2	86.5	10
1	2	I	915	136	2.6	80.6	10
1	3	I	1835	137	3.1	85.1	10
1	4	A	1910	144	2.7	86.9	10
2	5	I	2304	146	2.0	82.3	10
2	6	I	2781	153	2.6	84.8	10
2	7	A	2822	148	1.9	80.7	10
2	8	A	2975	142	2.3	81.9	10
3	9	I	2705	139	1.9	81.1	10
3	10	A	3291	138	2.4	81.0	10
3	11	I	2528	139	2.4	82.2	10
3	12	A	2692	136	1.9	81.9	10
		Action (Mean ± SD)	2577 ± 605	141 ± 4	2.23 ± 0.31	83.1 ± 1.4	10 ± 0
		Inaction (Mean ± SD)	2178 ± 706	142 ± 6	2.43 ± 0.44	82.7 ± 1.7	10 ± 0

Note. TTE = time to exhaustion; HR_{end} = End exercise heart rate; RPM = revolutions per minute; RPE_{end} = end exercise perception of effort; A = action words; I = inaction words

5.4.4. Effect of Subliminal Action and Inaction Word Priming on End Heart Rate, End Lactate Concentration, Mean Cadence, and End RPE

Mean heart rate at exhaustion was 141 ± 4 beats per minute following subliminal action word priming and 142 ± 7 beats per minute following subliminal inaction word priming. The randomization test revealed that 59% of the means from the alternative treatment arrangements were at least as large as the true experimental mean. The difference in heart rate at exhaustion between conditions was therefore non-significant ($p = .59$). This outcome was similar for blood lactate ($p = .85$) at exhaustion (action: 2.23 ± 0.31 mmol·l^{-1}, inaction: 2.43 ± 0.44 mmol·l^{-1}), and mean cadence ($p = .75$) with a mean RPM of 83.1 ± 1.4 during action priming and 82.7 ± 1.7 during inaction priming. As RPE was rated at exactly 10 at exhaustion following every visit, the randomization test revealed no differences between conditions ($p = .99$).

5.4.5. Effect of Subliminal Action and Inaction Word Priming on RPE and Heart Rate at Iso-time During the TTE Test

The shortest TTE was just over 15 minutes. Mean iso-time RPE between conditions was therefore analysed at one minute intervals, from the first minute to Minute 15. Randomization tests between conditions iso-time revealed that RPE was significantly lower when action words were subliminally primed during the TTE test compared to inaction words at minutes 10, 11, 13, 14 and 15 (see Figure 5.1). Because TTE was substantially lower during one visit (Visit 2), in comparison to all other visits, data was plotted for RPE at each iso-time point with the values from Visit 2 excluded. Mean iso-time heart rate between conditions was also analysed at one minute intervals from Minute 1 to Minute 15 Randomization tests at iso-time revealed that heart rate was not significantly different between treatment conditions at any point (see Figure 5.2).

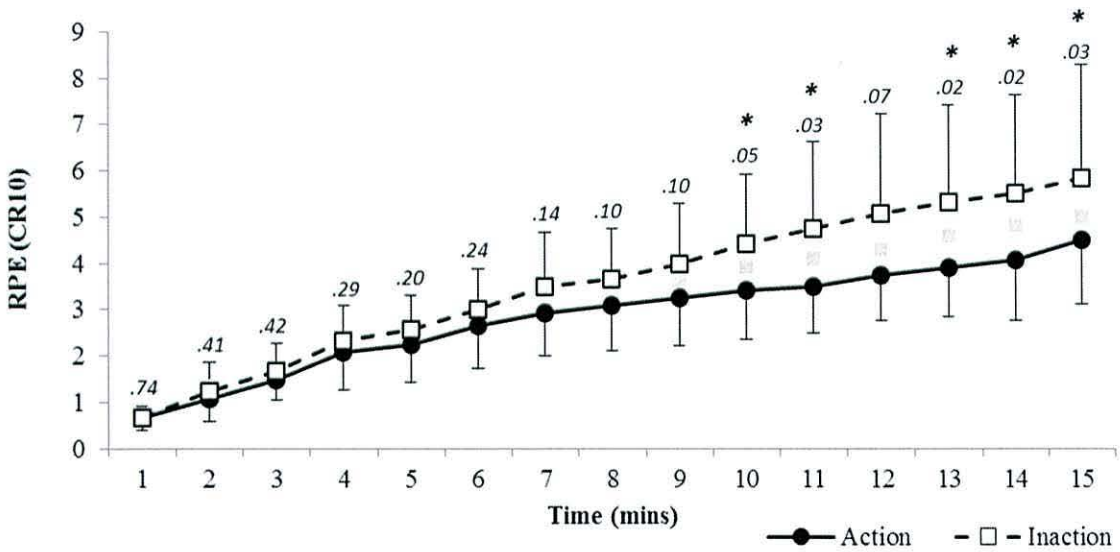

Figure 5.1. Mean (± *SD*) effect of subliminally primed action and inaction words on RPE at one minute iso-time intervals during first 15 minutes of the TTE. Grey markers show RPE for subliminally primed inaction words with visit two omitted. Value above each interval illustrates level of significance. * Indicates significant difference between treatments

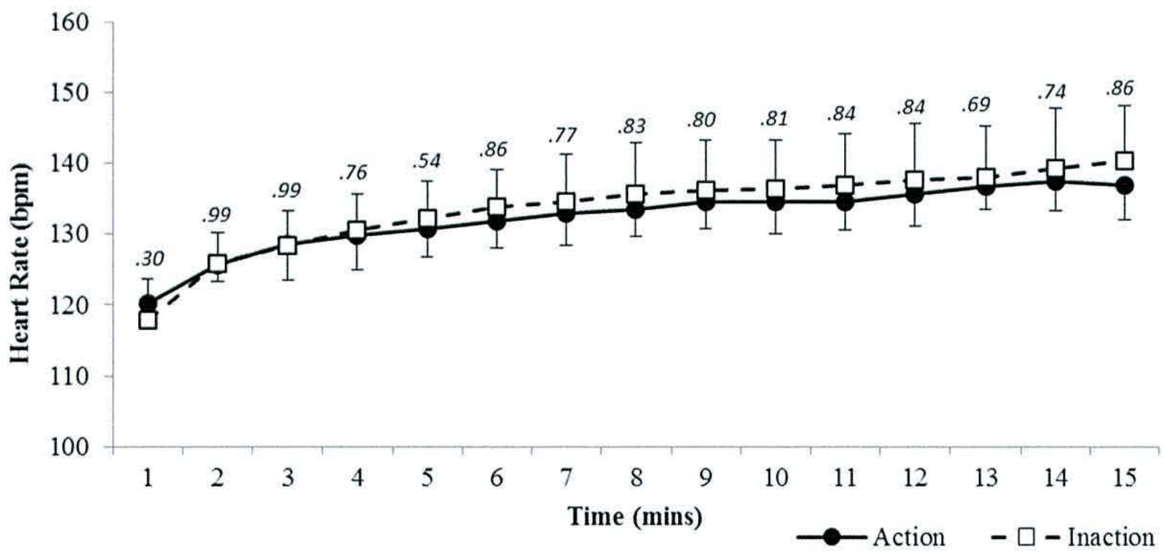

Figure 5.2. Mean (± *SD*) effects of subliminally primed action and inaction words on heart rate at one minute iso-time during first 15 minutes of the time to exhaustion test. Value above each interval illustrates level of significance.

5.5. Discussion

This study investigated the effect of subliminally primed action and inaction words on cycling TTE and RPE. In addition, this was carried out using randomization tests in order to demonstrate the utility of experimentally controlled and statistically evaluated single subject designs in sport and exercise science. As hypothesized, the findings of this study illustrate that TTE was significantly greater when action words were subliminally primed as opposed to inaction words. This greater TTE was also accompanied by a significantly lower RPE at various stages of exercise when action words were primed.

The current findings are in agreement with those of Albarracin et al. (2008) who found that the priming of general action words facilitated greater motor based activity in comparison to the priming of inaction words. Furthermore, these findings support those of Gendolla and Silvestrini (2010) who reported that subliminally primed action and inaction words were able to alter task related effort investment. The present study is the first to build upon these earlier reports by demonstrating that subliminally primed action and inaction words can impact upon performance and effort during whole body endurance based tasks. Accordingly this generates a platform for future research involving interventions for endurance enhancement in athletes and clinical populations.

Research illustrating the effects of action and inaction words on effort has been placed within the context of motivational intensity theory (Brehm & Self, 1989). For instance, Silvestrini and Gendolla (2013) reported that suboptimally primed action and inaction words could influence effort providing that task success was regarded as possible and worthwhile. In particular, during cognitive tasks that were regarded as easy or difficult, but nonetheless possible, primed action words elicited greater effort investment than primed inaction words. In the present study RPE was actually lower when action words were primed in comparison to inaction words. Consequently, TTE was greater during action word priming because the participant was able to cycle for longer before they reached their maximum RPE. Hence, action and inaction word priming altered the point at which continuation in the task seemed impossible. This supports the prediction made by the psychobiological model of endurance performance (Marcora, 2008), based on motivational intensity theory, that any physiological or psychological factor effecting RPE will effect physical endurance.

At first the findings of the present study appear to be inconsistent with those of Gendolla and Silvestrini (2010). This is because Gendolla and Silvestrini (2010) reported increases in effort investment during action word priming. In contrast RPE was lower when action words were primed in the current study. This discrepancy however can be plausibly explained by differences in test design. For example, in the current study the constant intensity nature of the TTE test clamps exercise intensity to ensure that it is equivalent between treatment conditions for the duration of every visit. Increases in exercise intensity owing to greater effort investment are therefore impossible with this design. With this in mind it is likely that the effect of primed action words is different when objective task difficulty is held constant; namely an equal exercise intensity can instead be maintained at a lower momentary RPE. Alternatively, it is possible that action words did not alter RPE in this case and that instead inaction words made the task seem more effortful, causing the participant to withdraw earlier in the TTE test. This alternative consideration poses one potential limitation regarding the choice of a TTE on this occasion; specifically because the clamped exercise intensity may have restricted the possibility to detect an effect of action words on RPE. This is because it is impossible to voluntarily increase momentary effort in this type of task as exercise intensity is automatically held constant by the apparatus. Future work should therefore attend to this by using a closed loop task to permit increases in exercise intensity. Such an approach may instead be able to directly support the findings of Gendolla and Silvestrini (2010) due to the prospect that subliminal word priming instead prompts individuals to increase momentary effort investment.

To some extent this bolsters the concept that RPE acts as a key limit to physical endurance (Marcora, 2008). This is because, it is not clear presently how subliminally primed words would alter the point at which physiological processes inhibit the ability of the muscles to persist with the task. To provide some support to this, measures of heart rate, mean cadence, and end exercise lactate were not significantly different between treatments. This is in agreement with other studies that have reported RPE related alterations in TTE (Marcora et al., 2009; Martin, 1981; Sgherza et al., 2002). Thus the influence of these basic parameters, along with pre-exercise mood and motivation, can be ruled out.

The present study was designed to build upon previous research to establish the effect of subliminally primed action and inaction words on RPE during a dynamic physical endurance task. It was therefore beyond the scope of this investigation to elucidate the mechanisms responsible for any differences in RPE and physical endurance that resulted from action and inaction word priming. Nonetheless, possible causes can be gleaned from the relevant literature. Gendolla and Silvestrini (2010) have for example suggested that the priming of general action and inaction words can activate a matching mental representation that influences effort. In particular, these prime concepts (i.e., action or inaction) are suggested to be goal motivated end states such that the priming of action words activates the goal to pursue contextually relevant active behaviour whereas inaction words activate the goal of inaction and thus task termination (Albacerrin et al., 2011). It is possible therefore that action and inaction priming in this study activated the corresponding mental representation to pursue task continuation or to cease the task respectively.

Another possible explanation for the present findings can be ascertained from a similar area of research demonstrating that action words are represented in, and automatically activate, the motor areas of the brain (Pulvermüller & Fadiga, 2010). Indeed, previous studies have shown that action words can automatically influence motor activation leading to greater grip forces (Aravena et al., 2012), increased postural sway during a balance task (Rodriguez, McCabe, Nocera, & Reilly, 2012), and increased vertical jump height during an explosive power task (Rabahi, Fargier, Rifaf Sarraj, Clouzeau, & Massarelli, 2013). It is conceivable therefore that action words directly sustained motor output towards the latter point of the TTE tests. This would provide a reasonable explanation for why the participant was able to cycle for 17% longer when continuously primed with action words.

Somewhat in line with this, it has been reported that the sensitivity to non-conscious reward priming increases as effort becomes more pronounced (Bijleveld, Custers, & Aarts, 2012). As such it is also possible that the word primes became more influential as the TTE test progressed and RPE correspondingly increased. Intuitively such an effect would exacerbate the desire for task termination during inaction word priming with the opposite effect manifesting as an increased willingness to continue with the task at high levels of effort during action word priming. It should however be noted that this is not a finding that has currently been investigated within the context of action and inaction words or physical endurance. It does however present an interesting opportunity for future research.

A second aim of this investigation was to exhibit the use of experimentally controlled and statistically analysed single subject designs. For this, randomization tests (Duggard et al., 2012) were implemented as they provide the experimental rigor of full treatment randomization along with a statistical measure of significance between treatments. In the present study, this approach permitted a scientific insight into the specific effects of subliminally primed action and inaction words on the participant in question. Such a personally tailored approach is an important but presently underused concept in sport and exercise science; not least because it permits a level of individual insight that cannot be acquired through group based inferences to a population. This method is particularly valuable in scenarios where knowledge of individual effects is paramount, or where the acquisition of sufficient sample sizes are problematic (Ploutz-Snyder, Fiedler, & Feiveson, 2013). Such scenarios may include those involving elite athletes, clinical conditions, or extreme situations such as military operations or spaceflight. This approach can also be used to acquire pilot data or to form a larger planned experiment in which a number of single subject interventions are collated to permit the meta-analytical evaluation of a concept (Dugard et al., 2012).

Despite the acknowledged benefits of randomization tests, the limits of this approach and this study in general should be considered; particularly given the scarce use of these tests at present. Pertinently, randomization tests lack any ecological validity beyond that of the individual investigated. Wider generalization of the present findings is therefore not possible. This is particularly exemplified by the present intervention. Namely because although the current participant appeared to respond more favourably to action words than inaction words, it is possible that individual responses to certain stimuli are moderated by factors such as previous experience with that stimuli, i.e., individual mental representations or schemas relating to that specific stimuli. Hence, especially in the case of a manipulation that involves learned stimuli such as words, it is plausible that large inter-individual differences may be evident in the way that individuals respond to certain primes. In addition some designs are difficult to administer, such as those involving longitudinal training interventions and treatments that require a prolonged washout period. Similarly, as with any longitudinal research, it is a risk that learning effects or training effects may manifest as the intervention progresses. Moreover the consequences of participant attrition or non-adherence in this type of design may be much more pronounced.

Various observations in the present study can be used to typify the considerations associated with randomization tests. For instance, a progressive increase in TTE is evident throughout the intervention, irrespective of priming condition. This is possibly indicative of learning or training effects. Accordingly, familiarization is integral to this type of design in order to mitigate the effects of learning. Although one familiarization session was implemented prior to the current intervention on the basis that TTE tests may require less familiarisation than time trial tests (Hopkins, Schabort, & Hawley, 2001), it would have been more prudent to implement multiple familiarizations to ensure that the participant achieved a steady baseline performance before the intervention. It is advisable therefore that future designs include more familiarization sessions prior to the intervention.

Though familiarization is vital to any investigation, it is unlikely that the continual improvement in TTE is exclusively attributable to this. This is more plausibly a consequence of training effects. Unfortunately a training effect is difficult to verify in the present intervention. This is because despite instruction to do so prior to the intervention, the participant did not record global RPE ratings in their pre-supplied training diary. It is therefore impossible to establish training load throughout the study. Nevertheless, in anticipation of issues such as these, a blocked randomization design was implemented. This can safeguard against confounds such as familiarization and training effects as it ensures that the participant is randomly subjected to both conditions evenly throughout the intervention. Therefore, as highlighted succinctly by the previous points, the implementation of a blocked randomized approach is imperative for sport and exercise interventions. Future research of this type should however consider using multiple blocks of just two randomizations per block in order to ensure greater certainty against threats to internal validity. This would likely exert superior control over these threats than the three blocks of four randomizations used in this study.

A further deliberation from the present design is the accuracy of the funnelled debriefing and prime recognition manipulation checks. This is because although the participant made 12 visits, within participant interventions only permit a funnelled debriefing procedure and a prime recognition task at their cessation. Unavoidably, these manipulation checks are therefore susceptible to recency effects. It is also clear that TTE in Visit 2 was markedly shorter than all others. This occurred despite the participant having adhered to all their instructions prior to the visit. Although the data from this visit may be a genuine result of the treatment manipulation, and should not be regarded as otherwise, it is also acknowledged that it could be anomalous. Unfortunately a weakness of randomization tests using a blocked approach is that it is not possible to statistically re-assess the data with this visit excluded. To somewhat account for this the raw data for RPE with this visit omitted has been included in Figure 1. On a similar statistical note, at present it does not seem possible to guard against Type I error inflation when multiple statistical tests are conducted with this design, for instance the simple randomization tests at each iso-time point. This should be considered when interpreting the data.

Finally, as no control group was used in the present study it is not possible to establish whether the present effects are a result of improved endurance following the use of action words, attenuated endurance following the use of inaction words, or a combination of both. While the addition of such as third control condition would have benefitted the interpretation of the findings though, it would have compromised other aspects; forcing either a reduction in the number of visits that could be allocated to each condition, or placing a heavier demand on resources and participant adherence. In this proof of principle study it was reasoned that establishing the existence of an overall subliminal priming effect was the most pertinent aim. Hence action and inaction treatment conditions were selected as opposed to one treatment condition along with a control group. However, the future addition of a control group would provide a more precise insight into the directional effects of action and inaction words during endurance exercise. This point is relevant for endurance performance enhancement as it would clarify whether primed action words can be used as a novel performance intervention. Alternatively, in consideration of an opposite effect, inaction words may be used to ensure that exercise intensity is curbed during a session that is intended to elicit minimal physical strain. This approach could be applicable from the perspective of recovery exercise.

The investigation of alternative word types such as anger words, or words associated with relaxation would be intriguing for future studies seeking to optimize competitive arousal or recovery. This is particularly relevant given the activation of mental representations accompanying word use, as suggested by Gendolla and Silvestrini (2010). On a similar note, it is important to establish whether conscious exposure to action and inaction words has a comparable effect on TTE and RPE. The action and inaction words in the present study were primed subliminally in order to conform to the previous methodology of Gendolla and Silvestrini (2010). However, if this priming procedure is also effective following the conscious exposure to primes, this has ramifications for the tailoring of training environments and verbal interactions with coaching staff or significant others. Lastly, the addition of functional magnetic resonance imaging during recumbent cycling would provide an insightful appraisal of the mechanisms involved in action and inaction word priming during endurance exercise. This is predominantly due to the possibility that these words may automatically activate the motor areas of the brain (Pulvermüller & Fadiga, 2010). Such an approach would extend the literature regarding the automatic activation of neural motor regions to elucidate the neural correlates of action and inaction words in conjunction with RPE.

In summary, subliminally primed action and inaction words altered TTE and RPE in the present participant. This finding provides a platform for additional group based investigations and research focusing on endurance performance enhancement. Moreover, while constrained by their generalizability, the findings somewhat support the psychobiological model of endurance performance; specifically that RPE acts as an important determinant of physical endurance and that any physiological or psychological factor effecting RPE will alter endurance. Finally, this study has highlighted the utility of randomization tests as a convenient method for statistically assessing single subject interventions. This statistical approach should be adopted more readily in sport and exercise science to collect information from restricted experimental contexts such those involving elite athletes, extreme clinical cases, and spaceflight.

CHAPTER 6

General Discussion

This chapter discusses and integrates the findings of all the experiments presented in this thesis. First, the main findings are contextualized in relation to the aims of the thesis. Alternative explanations for the findings are then suggested. Following this, the implications of these findings for both research and practical application are considered. The limitations of the thesis are then summarized with directions for future research subsequently proposed. Finally the main conclusions are presented.

The aim of this thesis was to identify possible strategies for modifying the limits to human endurance within the framework of the psychobiological model of endurance performance (Marcora, 2009). Based on the proposition that perceived effort (RPE) acts as a pivotal determinant of physical endurance (Marcora, 2009), the present thesis therefore sought to establish whether specifically selected psychological or psychobiological interventions were capable of directly targeting and altering RPE in order to provide a basis for future performance enhancing strategies.

The interventions that were implemented in each chapter were selected because of their psychological or psychobiological associations with effort (Barwood, Thelwell, & Tipton, 2008; Gendolla & Silvestrini, 2010; Marcora, Staiano, & Manning, 2009; Silvestrini & Gendolla, 2011). These interventions were motivational self-talk (Chapter 2), brain endurance training (BET; Chapter 3), subliminal affective priming (Chapter 4), and the subliminal priming of action and inaction words (Chapter 5). Surprisingly, none of these interventions had been experimentally used to investigate changes in RPE during endurance based physical tasks. This thesis therefore offers a distinctive perspective on psychobiological approaches to endurance performance. In doing so it contributes a number of novel interventions that may be implemented or further explored within the context of endurance performance enhancement. Correspondingly, each chapter also provides its respective field of investigation with novel insights that may be used as a general primer for future research.

These selected psychological and psychobiological interventions were able to alter the limits to physical endurance with varying degrees of success. In Chapter 2 motivational self-talk significantly prolonged cycling time to exhaustion (TTE) by 18%. Similarly in Chapter 3, though non-significant, BET prolonged TTE by 18% when individuals exercised at 65% peak power output (PPO). Conversely at 80% PPO TTE was instead reduced by 11% following BET. In Chapter 4, individuals were able to cycle for significantly longer (12%) when subliminally primed with happy affective cues compared to sad affective cues, while the single subject approach used in Chapter 5 illustrated that cycling TTE was significantly greater by 17% following the subliminal priming of action words versus inaction words.

To contextualize these findings against the original aims of the thesis, the psychobiological model of endurance performance predicts that physical endurance is determined by conscious and voluntary decision making rather than physiological processes (Marcora, 2009). Consequently, individuals voluntarily decide to terminate endurance exercise because of their conscious appraisal of effort and not because of physiological muscle fatigue. According to the psychobiological model of endurance performance, RPE is therefore a pivotal determinant of physical endurance (Marcora, 2009; Marcora & Staiano, 2010).

This principle that RPE is a pivotal determinant of physical endurance partly originates from evidence showing that individuals terminate exhaustive physical tasks when RPE is at or near maximum (Crewe, Tucker, & Noakes, 2008; Jacobs & Bell, 2004; Marcora & Staiano 2010; Presland, Dowson, & Cairns, 2005). The findings from Chapters 2, 3, 4, and 5 are all in agreement with this. Specifically, individuals terminated exercise at or near maximum RPE in all TTE tests regardless of the experimental intervention. This consistent finding therefore supports the concept that endurance was limited in these TTE tests because of a voluntary decision to terminate exercise resulting from a very high RPE.

Owing to the seemingly pivotal nature of RPE in physical endurance tasks, the psychobiological model of endurance performance also predicts that any physiological or psychological factor affecting RPE will affect endurance performance (Marcora, Bosio, & de Morree, 2008). Chapters 2, 4, and 5 are in support of this while Chapter 3 is presently inconclusive. Specifically, in Chapter 2 the use of motivational self-talk was able to significantly reduce RPE. As predicted, this corresponded with an increase in TTE. Similarly in Chapter 4, RPE was significantly lower when individuals were subliminally primed with happy faces compared to sad faces. Once more, this lower RPE also corresponded with a significantly greater TTE. Like Chapter 4, the approach used in Chapter 5 illustrated that it is possible for RPE to be reduced and TTE to be enhanced through subliminal priming. This chapter however extended the findings of Chapter 4 to show that the priming effect is not restricted to affective facial cues but is also evident during the priming of action and inaction words. Additionally, Chapter 5 highlighted the merits of using a robust methodological single subject approach to establish the precise individual effects of interventions such as these. In Chapter 3 neither RPE nor TTE were significantly altered at either exercise intensity following BET. Nonetheless, BET did have a practically beneficial effect on TTE at an exercise intensity of 65% PPO.

The findings from Chapters 2, 4, and 5 can be explained within the framework of the psychobiological model of endurance performance. Based on motivational intensity theory (Brehm & Self, 1989; Wright, 2008), this psychobiological model suggests that voluntary task termination may occur for one of two reasons. For instance, task termination may occur when individuals reach the highest RPE that they are willing to experience in order to succeed in a task; this is known as potential motivation. Alternatively, task termination may occur because the conscious RPE reaches such an excessive level that continuation in the task seems impossible.

When highly motivated individuals perform exhaustive open loop tasks that consist of no designated end point, they are fundamentally willing to exercise until maximum. In such circumstances, potential motivation is reached at maximum RPE and should not determine the point of voluntary task termination. Hence, task termination in these scenarios is instead dependent on the point when RPE becomes so extreme that continuation appears impossible. In Chapter 2, because motivational self-talk successfully reduced RPE during the TTE test, participants were able to cycle for longer before they reached their maximum RPE. As such, this may have delayed the point at which individuals voluntarily terminated the TTE test because continuation seemed impossible. Accordingly, motivational self-talk allowed individuals to surpass their previously perceived endurance limit. Likewise in Chapter 4, RPE was lower when individuals were subliminally primed with happy faces. Consequently, in comparison to their priming with sad faces, it took longer to reach to reach the point at which a high RPE made continuation in the TTE test appear impossible. Again therefore, individuals perceived endurance limits were greater when they were subconsciously primed with happy faces. Similar to Chapter 4, in Chapter 5 the subliminal priming of action words, in comparison to inaction words, permitted the participant to cycle for longer before reaching the point that continuation in the TTE appeared to be impossible. Once more this was in conjunction with a reduction in RPE.

In Chapter 3 BET was not able to statistically reduce RPE at either 80% PPO or 65% PPO. In addition TTE was not statistically altered at either intensity. Possible reasons for this have already been covered in the chapter. In brief however, it appears that at 80% PPO, BET in its present format is not an effective method of targeting RPE to enhance endurance. At 65% PPO it is possible that the intervention was subject to insufficient statistical power. As such, the findings from this chapter cannot be conclusively evaluated within the context of the psychobiological model of endurance performance. Primarily because the concept that any physiological or psychological factor affecting RPE will affect endurance performance cannot be either validated or rejected at present.

Support for the general findings of Chapters 2, 4, and 5 can be gathered from a variety of situational contexts associated with motivational intensity theory, as well as a number of findings from endurance exercise interventions. For instance Chapter 4 is in direct agreement with behavioural studies evidencing alterations in effort when affect is manipulated both consciously (Gendolla & Krüsken, 2002) and subconsciously (Silvestrini & Gendolla, 2011). Specifically these studies report increased appraisals of effort during the priming of negative affect in comparison to the priming of positive affect. Beyond affective states, greater perceived ability is known to reduce effort and appraisals of task demand (Wright & Dill, 1995), as is greater levels of physical (Wright, Shim, Hogan, Duncan, & Thomas, 2012) and mental fatigue (Wright, Stewart, & Barnett, 2008). Mental fatigue is also known to increase RPE during physical tasks. This is proposed to hasten the point at which continuation in exhaustive physical tasks is regarded as impossible (Marcora et al., 2009). A similar conclusion has also been drawn following locomotor muscle damage with RPE becoming more pronounced, and physical endurance curtailed, during a cycling TTE test (Marcora et al., 2008). When this is considered alongside similar findings from other interventions such as sleep deprivation (Martin, 1981), and psychostimulant manipulation (Jacobs & Bell, Sgheza et al., 2002), the direct effect of psychobiological interventions on effort related processes appears relatively conceivable.

6.1. Alternative Explanations

It was beyond the scope of this thesis to explore the effect of physiological muscle fatigue on physical endurance or RPE. Hence the general effect of physiological muscle fatigue in the present chapters cannot be comprehensively evaluated. Nonetheless, it would be remiss not to discuss this topic; particularly as the psychobiological model of endurance performance is established on the basis that RPE acts as the pivotal determinant of physical endurance, rather than physiological muscle fatigue (Marcora, 2009).

Regarding the limits to physical endurance, MacIntosh and Shahi (2011a) contend that highly motivated subjects who are familiar with a task will persist until the muscles are no longer capable of producing the necessary force or power. In addition, this inability to produce the necessary force or power has been directly associated with processes residing in the working muscles (Allen, Lamb, & Westerblad, 2008). Moreover, it is suggested that these involuntary processes may also cause the rise in RPE (MacIntosh & Shahi, 2011b). On this basis it is initially plausible that exercise was limited in Chapters 2, 3, 4, and 5 because of physiological muscle fatigue. This would also provide a different perspective on why exercise culminated at or near maximum RPE. However, no significant differences in physiological parameters such as heart rate or post-exercise lactate were evident in Chapters 2, 4, or 5. Yet, changes in RPE and TTE were still evident. This is in agreement with other studies that have measured RPE using constant intensity TTE tests (Jacobs & Bell, 2004; Martin, 1981; Marcora et al., 2009; Sgherza et al., 2002). Therefore, in conjunction with conclusions from these studies (Marcora et al., 2009; Sgherza et al., 2002), the influence of the physiological factors above cannot explain the changes in RPE or TTE in the present chapters.

Although heart rate and post-exercise lactate were not significantly different in Chapters 2, 4, or 5, it is important to acknowledge that the proposed causes of physiological muscle fatigue extend beyond these basic physiological measures. For instance, Allen et al. (2008) have suggested that inorganic phosphate can inhibit calcium release in the muscle cell and Fitts (2008) suggests that adenosine diphosphate accumulation can inhibit excitation contraction coupling. More complex physiological parameters such as these were not measured in Chapters 2, 4, and 5 thus their effect on RPE and TTE in these chapters cannot be experimentally ruled out. Despite this, the influence of such parameters may still be probed through logical reasoning. For instance, if muscular processes do limit physical endurance, it is not presently clear how they may be regulated by psychological or psychobiological interventions. Specifically, it is difficult to conceptualize scientifically why a physiological limit may change following the exposure to visual subliminal cues (Chapters 4 & 5), or why the manifestation of such a limit would be delayed by motivational self-talk (Chapter 2).

In further support, constant intensity TTE tests were used throughout this thesis to eliminate the effects of individual pacing. Physiologically, this should ensure that within participant fluctuations are minimised between visits. Hence, if physical endurance limits are determined by physiological muscle fatigue, this experimental approach should only highlight significant differences in RPE and TTE after physiological interventions. Conversely, the chapters in the present thesis involved no physiological manipulations, instead focusing exclusively on psychological or psychobiological interventions. As such, it is more feasible that factors other than physiological muscle fatigue were responsible for the findings in Chapters 2, 4, and 5.

As it is difficult to rationalize how muscular processes may explain the findings in Chapters 2, 4, and 5, alternative models of physical endurance should also be considered. In this regard, the afferent feedback model (Amann, 2012) and the central governor model (Noakes, 1997) posit that the mechanical and biochemical stimulation of group III and IV muscle afferents within the working muscles may limit physical endurance by restricting central motor drive. Moreover, in each model it is proposed that this restriction on central motor drive serves as a critical threshold (Amann et al., 2009) to limit the level of excessive muscle dysfunction (Amann, Proctor, Sebraneck, Pegelow, & Dempsey, 2009) or to avert catastrophic perturbations in homeostasis (Noakes, 2012).

Presently, it is difficult to place the findings from Chapters 2, 4, and 5 within the framework of the afferent feedback model (Amann, 2012). This is for both speculative and experimental reasons. For instance, speculatively this model is comparable to that of physiological muscle fatigue. It is therefore difficult to surmise how a psychobiological intervention involving motivational self-talk (Chapter 2) or subliminally primed cues (Chapters 4 & 5) may alter mechanical or biochemical feedback from the muscles. More importantly however the suggestion that a critical threshold exists to regulate central motor drive to the muscles is also problematic experimentally. In particular, Amann et al. (2009) found that cyclists displayed signs of excessive physical fatigue and a reduction in 5 km time trial performance following the blockade of group III and IV muscle afferents. This is proposed as evidence that surpassing this critical threshold may elicit excessive physiological fatigue (Amann et al., 2009). In the present thesis however a two week protocol of motivational self-talk (Chapter 2) permitted individuals to exceed their previous physical limit by 18%. This was without signs of excessive physical fatigue; hence, it unlikely that a critical threshold for afferent feedback was responsible for task cessation during this chapter.

Although not as emphatically illustrated as Chapter 2, it is also challenging to understand why individuals would reach a critical physiological threshold at different points during exposure to subliminal primes (Chapters 4 & 5). This becomes more pertinent when considering that RPE is proposed to be caused by afferent feedback (Amann, et al., 2013). Nonetheless, RPE was significantly altered following the interventions in each of Chapters 2, 4, and 5. This is despite the fact fluctuations in afferent feedback between visits would likely have been minimized by the use of constant intensity TTE tests. While it should be highlighted that the exercise test utilized in the Amann et al. (2009) study was different to those used in this thesis, the present considerations suggest that the findings in Chapters 2, 4, and 5 are unlikely to be attributable to changes in afferent feedback.

Like the afferent feedback model, the central governor model (Noakes, 1997) regards afferent feedback to be key regulator of physical endurance. As such, early versions of this model excluded the role of psychological processes, attributing alterations in central motor drive solely to afferent processes. This is because muscle recruitment was proposed to be regulated at a subconscious level to inhibit conscious override, and mitigate homeostatic impairments (Noakes, 2000). More recent versions have integrated the role of feedforward processes such as teleoanticipation and motivation (Noakes, 2011). Accordingly, the recent versions of this model may provide plausible alternatives for the findings in this thesis. However, a number of discrepancies and uncertainties should also be addressed.

Primarily, despite clear progression of the central governor model (Noakes, 1997; Noakes 2012; Noakes, St Clair Gibson, & Lambert, 2005), a lack of clarity persists regarding the precise mechanism that limits endurance. For instance it remains unclear whether this model proposes that endurance is limited by restrictions on central motor drive that emanate from a complex and intelligent system (Noakes, 2011), or conscious and voluntary decision making owing to a high RPE (Crewe, Tucker, & Noakes, 2008; Noakes & Tucker, 2008). In conjunction with this, it is proposed that teleoanticipatory processes set RPE at the commencement of exhaustive tasks to determine exercise duration (Crewe et al., 2008). Despite the reference to RPE, this appears to implicate a pre-determined process. Moreover this concept of pre-emptive teleoanticipation is incompatible with the findings of Chapter 2 in which motivation self-talk significantly enhanced TTE, despite no significant differences in RPE at 0% iso-time. This suggests that the increase in TTE could not have been meditated by early teleoanticipatory regulation. Later versions of this model do however hint at proposals that this teleoanticipatory process may be more momentary and ongoing (Noakes, 2012)

Another key consideration of the central governor model is the convergence of afferent feedback and feedforward teleoanticipatory processes to regulate central motor drive and protect the organism from major homeostatic perturbations. Similar to the afferent feedback model, it is difficult to comprehend why the organism may permit the encroachment of a critical threshold that is proposed to protect homeostasis. Nevertheless this would have to occur to elicit the improvement in TTE following motivational self-talk (Chapter 2). Recently, the existence of a central motor reserve that may exceed this threshold under certain circumstances has been proposed (Swart et al., 2009). From an evolutionary perspective this makes teleological sense. Nevertheless, this proposition still lacks genuine experimental support. Moreover, the frequency and apparent ease with which such a reserve appears to be accessible (cf. Noakes, 2012) renders it somewhat redundant. This is epitomized by the manifestation of exercise related collapse; an occurrence that is suggested to result from psychological drives (St Clair Gibson et al., 2013). In comparison to the action of a complex and intelligent system that controls central motor output, a notion such as this is therefore more reflective of willed and voluntary decision making; albeit in these extreme cases, culminating in a severe physiological limit.

A final intriguing perspective arises from arguments concerning the concept of free will (Shepherd, 2012). This perspective debates that consciousness and volition are not the direct cause of action but are merely illusory by-products of stimulus driven reflexes (Bonn, 2013). Hence the awareness of a conscious will to act occurs after the neural impulse to perform an action is formed. For instance Libet, Gleason, Wright, and Pearl (1983) reported that the awareness of conscious will arose several hundred milliseconds after the impulse to perform an action had been formed within the motor areas of the brain. Soon, Brass, Heinze, and Haynes (2008) also found that subjective awareness occurred up to 10 seconds after the neural indicators of action had formed within the supplementary motor area.

Such an argument against free will directly opposes the suggestion that task termination is dependent on conscious and voluntary factors. It could therefore be used to corroborate physiological muscle fatigue (MacIntosh & Shahi, 2011a) or supraspinal fatigue (Amann et al., 2013) as the pivotal determinants of endurance performance and RPE; primarily as these are thought to result from involuntary processes (Marcora, 2009). Nonetheless this explanation for the present findings is still problematic. Namely, it requires that psychological interventions alter the processes involved in physiological muscle fatigue so that physiological exhaustion is delayed (Chapter 2), or at least altered (Chapters 4 & 5). As already pointed out however, and agreed by others (St Clair Gibson et al., 2013), how psychological interventions should modify physiological processes in such a manner is yet to be scientifically clarified.

In sum, alternative explanations relating to physiological muscle fatigue are presently difficult to place within the findings of this thesis. Furthermore, though it is not disputed in this section that group III and IV muscle afferents might contribute to changes in physical endurance (Amann et al., 2008; Hilty, Langer, Pasqual-Marqui, Boutelier, & Lutz, 2011; Noakes, 2012), it is difficult to attribute these processes to the findings in Chapters, 2, 4, and 5. This is because they cannot clarify scientifically for now how psychological interventions may influence afferent feedback to cause physiological exhaustion (St Clair-Gibson et al., 2013). For the time being the most plausible explanation for Chapters 2, 4, and 5 is that each targeted psychobiological intervention directly altered RPE and modified the point at which these individuals consciously perceived maximum effort and hence voluntarily terminated endurance exercise.

6.2. Practical Applications

Chapters 2, 4 and 5 add to a growing body of research to suggest that changes in RPE lead to significant changes in physical endurance (Jacobs & Bell, 2004; Marcora et al., 2008; Marcora et al., 2009; Sgherza, 2002). These chapters therefore advocate a complementary approach to endurance performance enhancement that considers the psychobiological model of endurance performance. This approach emphasizes the implementation of specifically selected strategies to directly target reductions in RPE during physical endurance tasks. Though some of the chapters in this thesis support such an approach, it should nevertheless be heavily stressed that it was not an aim of this thesis to simultaneously dismiss traditional approaches to performance enhancement. Traditional approaches to endurance performance enhancement are correctly regarded as effective; in particular physical training interventions and nutritional interventions (Helgrued et al., 2007; Jentjens, Achten, & Jeukendrup, 2004). The psychological and psychobiological interventions used in the thesis should consequently be viewed as an adjunct to these traditional strategies rather than a replacement.

Despite this, the practical implications of the interventions in this thesis are best contextualized when their effects are compared against already well-established physiological findings. For instance the potential impact of implicit affective cues (Chapter 4) and subliminally primed action and inaction words (Chapter 5) are accentuated when they are displayed against the effects of various physiological manifestations that are suggested to effect endurance performance. In particular, the 12% difference in TTE caused by happy and sad implicit primes in Chapters 4 is comparable to the negative effects of inspiratory muscle fatigue (14%; Wüthrich, Notter, & Spengler, 2013), and locomotor muscle fatigue (18%; Marcora, Bosio, & de Morree, 2008). Moreover the 17% difference between implicit action and inaction word priming in Chapter 5 is somewhat comparable to the detrimental effects of cycling while dehydrated versus cycling while consuming fluids (24%; Arnaoutis, Kavouras, Christaki, & Sidossis, 2012), and also cycling in a low versus a normal carbohydrate state (27%; Lima-Silva, De-Oliveira, Nakamura, & Gevaerd, 2009).

Like Chapters 4 and 5, the potential efficacy of motivational self-talk in Chapter 2 is signified by the fact that the 18% increase in TTE is comparable to the supplementation of dietary nitrate which has been shown to prolong cycling time to exhaustion by 17% (Kelly, Vanhatalo, Wilkerson, Wylie, & Jones, 2012). Moreover, the ingestion of psychostimulant drugs have been shown to prolong TTE by 28% when compared to a control condition; however this comparison to motivational self-talk becomes more relatable when the effects of this drug are compared to that of the placebo condition (17%; Jacobs & Bell, 2004). Furthermore, while the findings from Chapter 3 were non-significant, direct comparison of the 18% increase in TTE at 65% PPO following BET also illustrates clearly the necessity to follow up this intervention with more comprehensive studies.

Although various chapters in this thesis offer preliminary statistical support for a psychobiological approach to performance based interventions; because of their relative emphasis on performance, it was also necessary to evaluate the practical significance of these chapters. To do this, a magnitude based inferences approach was implemented alongside traditional statistical analysis (Batterham & Hopkins, 2006). This approach permits researchers and practitioners to assess the practical benefit of a performance strategy with greater scope than that offered by null hypothesis significance testing alone. A synopsis of the practical findings from Chapters 2, 3, and 4 in relation to their standardized effects on TTE is illustrated in Figure 6.1. In Chapter 2, not only was the use of motivational self-talk found to statistically reduce RPE and enhance TTE, this strategy was also found to have a *very likely* practical effect on endurance and a *likely* practical effect on reducing RPE. In Chapter 3, despite not attaining statistical significance, BET was found to be of *likely* practical benefit on TTE at 65% PPO. The practical value of BET on TTE at 80% PPO was nonetheless found to be *unclear*. Lastly, in Chapter 4 the difference in implicit affective priming was found to be of *possible* practical importance on TTE. While it is accepted that the directional effect of this *possible* practical importance in Chapter 4 is not known, this nonetheless has meaningful practical implications for the impact of implicit affective cues during endurance exercise. Moreover it provides a basis for performance enhancing interventions designed to capitalize on the effect of implicit cues (see Future Directions).

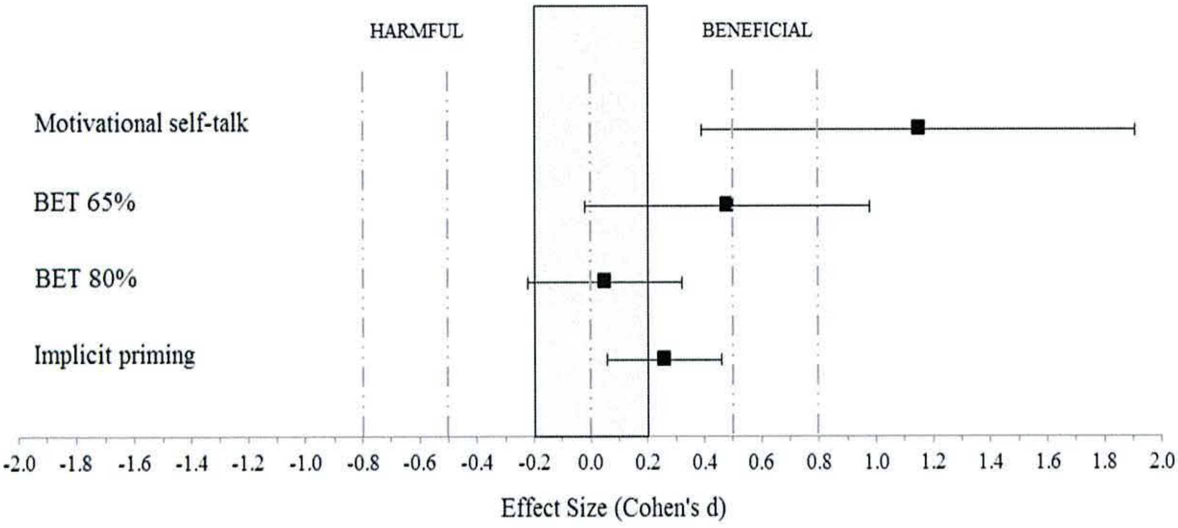

Figure 6.1. Standardized Cohen's *d* effect size (± 90% CI) for each intervention (y-axis) on time to exhaustion. Positive values indicate a difference in favour of the experimental groups or a difference between implicit affective priming conditions. Shaded area represents the region in which the difference is trivial (i.e., -0.20 to 0.20 standardized effect sizes).

The practical implications of Chapter 5 are slightly different to those of the preceding chapters in the thesis. This is because of the alternative experimental design that was adopted in this chapter. A single subject approach was implemented in Chapter 5 specifically to exhibit the utility of randomization tests in both practical and research based settings. The findings illustrate that this approach can be used to establish whether a specific intervention is statistically likely to be of practical value to on an individual basis. Accordingly, certain interventions may be tailored to, or excluded from, personalized training plans more precisely. This is something that may be particularly applicable to acute interventions such as nutritional supplementations, psychological strategies, and post-exercise recovery methods.

Considering these practical findings, Individually Chapters 2, 3, 4, and 5 demonstrate the preliminary efficacy of each of the interventions used in this thesis as possible strategies for endurance performance enhancement. Collectively, they also emphasize the practical impact of targeting alterations in physical endurance using RPE based psychological or psychobiological interventions. Alongside this, three points of general practical importance can also be gleaned. Firstly, during group based interventions that directly explore performance, scientific conclusions based on null hypothesis significance testing would benefit from the additional assessment of magnitudes of effect and practical significance. Secondly, an intervention demonstrating non-significant findings, as in the case of Chapter 3, may still be practically important and should not be overlooked due to its lack of statistical significance. Finally, athletic training plans can be precisely tailored by using randomization tests to identify whether findings that emerge from group based designs are statistically applicable to a specific individual.

6.3. Limitations

In order to thoroughly contextualize academic research it is important that the limitations of that research are also considered. Despite the encouraging findings of the present programme of research, it is therefore imperative that its shortcomings are discussed. Firstly for example, it is evident that the studies presented are comprised of only a narrow scope of exercise intensities, and hence exercise durations. In addition, the studies focus on only one exercise modality. Moreover, the individuals sampled within each study may only be regarded as recreational endurance athletes. While this consistent and planned approach can be regarded as a strength due to its uniformity, it also restricts the scope of generalisations that can be assembled from the research.

Due to the relatively brief duration of the endurance bouts that are implemented in the present thesis, it is not possible to declare that the strategies implemented in each chapter will be effective during more prolonged endurance tasks. In Chapter 3, the effects of BET were investigated at two separate intensities in order to somewhat account for this. However the task conducted at 65% PPO is still relatively short in comparison to longer endurance bouts where factors such as endogenous fuel provisions are proposed to become more decisive (Jeukendrup, 2011). This is most succinctly exemplified during the 42 km marathon whereby individuals are frequently forced to reduce their pace towards the later stages. This inability to maintain a high intensity pace is attributed to the near complete depletion of carbohydrate stores in the liver and the working muscles (Rapoport, 2010). These fuel resources are not as threatened during bouts lasting less than approximately 90 minutes (Hawley, Schabort, Noakes, & Dennis, 1997) and the exhaustive bouts in the present thesis were notably shorter than this. Relatively few studies have explored the influence of RPE on endurance during longer duration bouts (Pires et al., 2011; Swart, Lindsay, Lambert, Brown, & Noakes 2012). The contention that conscious and voluntary factors such as RPE are the principal determinant of endurance over longer endurance bouts therefore still requires further investigation, as does the efficacy of the present interventions over these durations.

Although the reported limitations of open loop TTE studies have been addressed in Chapters 1 and 2 (Jeukendrup, Saris, Brouns, & Kester, 1996; Marino, 2012), this measure of endurance was used in all experimental chapters. While this was the most appropriate approach for investigating the present research, it is acknowledged that this may compromise the external validity of the findings. This use of open loop TTE tests provides an ideal proof of principle foundation from which future studies can be adapted. It also provides an optimal insight into the factors that limit endurance. The findings in their present context however should be approached with some educated interpretation when seeking to transfer them directly to performance scenarios involving time-trial events or the presence of competitors. In addition, it should also be recognised that the constant power output during each TTE was maintained in all chapters by setting the Lode Excalibur to hyperbolic mode. Although open loop TTE tests may therefore provide more control than time trial designs over any pacing induced physiological changes, cadence is free to vary in hyperbolic mode. This was implemented so as to eliminate any artificial deviations in preferred pedal rate. Nonetheless, it is possible that fluctuations in cadence may have elicited physiological changes via altered motor patterns (Dantas et al., 2009). As mean intra-individual differences in cadence did not exceed 2 RPM in any chapter however, this is unlikely in each of the present chapters.

It is clear that one of the key dependent variables in the thesis, RPE, was measured subjectively throughout. This is the most common method of measuring effort in exercise based scenarios (Noble & Robertson, 1996). Some inherent issues with this subjective measure are however of note. In particular Lamb, Eston and Corns (1999) reported that the test-retest reliability of the 16 point RPE scale was questionable during graded exercise tests with uncertainty reaching up to three RPE units at some levels of exercise intensity. While the present thesis did not utilize the 16 point scale or graded exercise tests, this finding is still important. In behavioural psychology, cardiovascular measures such as pre-ejection period have been used as objective markers of effort (Wright, 2008, Gendolla, 2012). Given the effect of exercise on the cardiovascular system the use of this objective measure was not possible in the present thesis. To ameliorate this, facial electromyography (EMG) was implemented to objectively measure effort in Chapter 2; however this was not used in subsequent chapters. This was primarily because the findings from Chapter 2 suggested that it may not be a sensitive measure of effort during psychological or psychobiological interventions. Also, previous research has suggested that this is not an effective measure of effort at lower exercise intensities (de Morree & Marcora, 2012). Thus for the lesser exercise intensities that were used in Chapters 3, 4 and 5, facial EMG was deemed unsuitable.

It has also been found that RPE is susceptible to measurement frequency. For instance, RPE is greater when measured at one minute intervals as opposed to ten minute intervals (Corbett, Vance, Lomas, & Barwood, 2009). Intuitively however, infrequent measurements may confer the risk of overlooking important changes in RPE. Accordingly at 80% PPO in Chapters 2 and 3, RPE was measured at one minute intervals. However at 65% PPO in Chapter 3, RPE was measured at three minute intervals. Upon completion of Chapter 3, it was deemed that at three minute intervals the risk of overlooking important changes in RPE was still possible. Accordingly, this measurement was reduced to two minute intervals at 65% PPO in Chapter 4, and further to one minute intervals at 65% PPO in Chapter 5. These alterations were based on the premise that if measurement error did exist, this error would be systematic across visits within each respective intervention. Moreover, observing momentary changes in RPE was reasoned to be more pertinent than potentially overlooking these changes via less frequent recordings. A final issue regarding the measure of RPE was that the Borg CR10 scale was used in all chapters in order to circumvent a ceiling effect on subjective ratings (Noble & Robertson, 1996). It is noteworthy however that no significant differences were evident at 100% iso-time in Chapters 2, 3, and 4. While it is possible that this is a true reflection of the data, it is also possible that despite explicit instructions to exceed a rating of 10 if necessary, participants did not do so. Hence a ceiling effect may still have occurred.

In Chapter 2 some of the issues regarding the administration of the control condition have already been acknowledged. For instance, while unlikely, the possibility that the findings could result from a placebo effect cannot be ruled out. Additionally however, non-treatment control groups are also exposed to other threats to internal validity such as resentful demoralisation and compensatory rivalry (Behi & Nolan, 1996). That performance and RPE remained extremely similar between the pre-test and post-test visits for the control group somewhat refute the effect of these threats in this instance. However this does not refute the notion that these threats were possible. Although the design of placebo groups for self-talk research can be difficult, in retrospect this study should have used an attention-control condition whereby control participants receive a credible sham treatment that reflects the experimental treatment in terms of duration and attention (Borg, 1984).

In Chapter 3, an attention-control condition was implemented to account for the shortcoming outlined in Chapter 2. As such, participants were informed that the daily inert nutritional supplement they were provided with contained an amino acid that was associated with endurance. While this represents an improvement on the approach implemented in Chapter 2, the demand placed on the attention-control participants in Chapter 3 was still inferior to the experimental group who underwent 22.5 hours of BET. This may have contributed to the greater participant attrition in the experimental group; therefore introducing a threat of differential mortality (Behi & Nolan, 1996). In Chapters 4 and 5 this latter threat was again eliminated by implementing a repeated measures design in which participants were informed that they were participating in an identical scenario during both experimental visits.

On a final note, magnitude based inferences were implemented Chapters 2, 3, and 4 as these chapters utilized group based experimental designs. This approach is a strength as it complements significance testing to illustrate the practical effects of a performance intervention. However, on previous recommendations (Batterham & Hopkins, 2006), the criteria for a smallest worthwhile change in each chapter was set arbitrarily as a small effect size (0.2), based on previously proposed thresholds (Cohen, 1988). This appraisal of practical treatment effects would have been more precise if the smallest worthwhile change had been based on an established criteria relating to recognised and worthwhile real world effects. Future interventions of this kind should seek to do this.

6.4. Future Directions

Naturally, many research investigations generate more questions than they serve to resolve. Those involved in this thesis are no different. To build upon this thesis a number of future directions are therefore worthy of pursuit. These future directions include those relating directly to performance enhancing interventions within the framework of the psychobiological model of endurance performance, more general considerations regarding RPE, and themes to rectify the acknowledged limitations of the present thesis chapters.

Specifically it would be interesting to combine Chapters 2 and 5 to investigate optimal methods of self-talk delivery. For example, establishing the efficacy of a more focused use of action words to modify RPE and endurance in comparison to the broader concepts of motivational or positive self-talk. On a similar level, examining the effect of implicitly delivered action words in comparison to the explicit use of action words via structured self-talk would provide some insight into the actual strength of implicit action word priming. The behavioural and perceptual responses to action or inaction words when vocalized explicitly by others may also indicate extent to which individuals are influenced by personality dynamics within performance environments. Finally on this theme, investigating the use of negative forms of self-talk for performance enhancement may offer a novel slant on the self-talk literature. For instance, the prospect that anger based self-talk may facilitate, as opposed to debilitate, effort and physical endurance is enticing based on findings from previous studies (Freydefont, Gendolla, & Silvestrini, 2012).

With regards to Chapters 4 and 5, initially obvious directions for the applied use of subliminal priming might be to employ computerized priming during physical training sessions. However a number of prerequisites should be resolved before this approach can be applied effectively. For instance, due to the ethical considerations associated with non-conscious priming, it must be established whether these primes work when individuals are aware that they are being primed. Likewise, it should be established whether these primes remain effective when delivered explicitly as opposed to implicitly. Nevertheless, even these approaches cannot circumvent the problem that individuals must be present at a computer for them to be implemented. Accordingly the exploration of pre-event priming, rather than priming during a task, would be applicable in this context. However, while these approaches represent worthy directions for future research, a less apparent direction is more appealing.

In particular, Chapter 4 was designed to preliminarily investigate whether individuals may be susceptible to implicit affective primes. This was to establish if a foundation for future performance enhancing research may exist, as opposed to serving as a means of performance enhancement of itself. As such a more practically applicable use of the findings from this chapter would be to focus on approaches designed to permanently modify implicit affective biases during endurance tasks. For instance, Chapter 4 hints at the possibility that individuals are susceptible to performance decrements when unwittingly exposed to negative affective cues. A two stage approach featuring the identification of populations or individuals who are most susceptible to these effects followed by interventions designed to permanently modify these implicit biases may therefore represent a more structured and productive tactic. Interventions such as attentional bias modification (Clarke, Notebaert, & MacLeod, 2014) or evaluative conditioning (Meerman, Brosschot, van der Togt, & Verkuil, 2013) may accordingly serve to more lastingly bias affective schema towards the implicit recognition of positive cues. As well as performance enhancement, this approach might have implications for talent identification and clinical populations suffering from debilitative fatigue.

Despite the non-significant outcome in Chapter 3, the *likely beneficial* practical effect of BET at 65% PPO offers some insight into the potential effects of this novel strategy. This *likely* practical effect is pertinent given that this was the first implementation of BET. Hence, modification of the protocol itself may provide a more definitive evaluation of this strategy in the future. Accordingly, targeting alternative neural structures such as the insular cortex may aid in the efficacy of BET. Moreover, although the tasks, session length, and the six week duration of the intervention were all guided by empirical findings, it is likely that some of these components would benefit from adjustment. In line with this an enticing alteration to

BET may involve the timing of the sessions themselves. For example, delivering the cognitive tasks immediately before or after endurance exercise may impose further demand on the individual and stimulate a more pronounced neural effect.

Two final aspects of future research relating to Chapter 3 can be taken from findings regarding RPE itself. Firstly, studies involving the psychobiological model of endurance performance should consider that RPE might not need to be reduced to signify an increase in performance. This is because it is plausible that interventions such as the present one instead prolong the amount of time for which individual is able to sustain high levels of effort. Future exploratory interventions involving RPE should therefore seek to investigate this more directly. Secondly, the reduction in TTE at 80% PPO in both groups intimates that these individuals experienced high levels of effort sooner following the intervention. This may be due to a catastrophizing of RPE owing to knowledge of the second TTE test. Although catastrophizing and fatigue has already been documented to some extent (Lukkahatai & Saligan, 2013), whether RPE may also be vulnerable to catastrophizing is seemingly still unknown. This proposition may have considerable implications for multi-event sports such as triathlon, training or competitive events that are conducted in close proximity to one another, or behaviour change interventions directed towards individuals who may simply avoid exercise due to an exaggerated appraisal of impending effort.

Based on some of the preceding limitations of the thesis, the most necessary directions for general research involve the implementation of the psychobiological strategies in Chapters 2, 3, 4, and 5 in more ecologically valid contexts. For instance, to be of value the effects of these interventions must also be evident in circumstances that reflect competitive endurance events. Scientifically evaluating these strategies during competitive closed loop scenarios is therefore imperative. It is equally important to identify the effects of these strategies on different populations to those used here. Specifically, investigating the effects of psychobiological strategies on clinical populations and elite performers would offer a rich and worthwhile avenue for future research. In addition, given some of the difficulties encountered with sample size and experimental control in these populations, the single subject design demonstrated in Chapter 5 typifies a fitting approach to this type of research.

Finally, as alluded to, before RPE can be accepted as the pivotal determinant of physical endurance, its influence must be scientifically assessed during prolonged endurance bouts that may be more susceptible to physiological limitations such as insufficient fuel stores. Moreover, more sophisticated and direct markers of effort must be established before perceived effort can be regarded as the ultimate determinant of physical endurance. It is also necessary to establish whether the psychobiological strategies presented in this thesis would be effective in such scenarios. For example, in Chapter 3 the discrepant practical benefit of BET at different exercise intensities intimates the contextual nature of these strategies. Similarly, an imperative area for future research when evaluating findings such as those in this thesis involves the integration of psychological strategies and more sophisticated physiological measurements during endurance exercise. It is of course possible that psychological interventions directly affect the processes involved physiological muscle fatigue. In many ways this would act as a testament to the strength of the psychological intervention. However, only by exploring psychological interventions in conjunction with a range of physiological measures can this be truly clarified. Without sufficient research to support this possibility, the conclusions drawn from this thesis, and future work, cannot extend beyond the experimental evidence available. More extensive physiological measurements must therefore be introduced alongside psychological interventions to explore the direct effect of psychological or psychobiological strategies on muscular processes.

6.5. Conclusions

This thesis has provided promising evidence to suggest that using psychological or psychobiological interventions designed to directly target RPE can significantly modify the limits to human endurance. While doing so, the thesis has highlighted a number of novel strategies that might be adapted for use alongside conventional methods to facilitate endurance performance enhancement. These strategies include motivational self-talk, the manipulation of implicit affect, subliminal action and inaction word priming, and possibly brain endurance training. Within the framework of the psychobiological model of endurance performance, this thesis therefore advocates an adjunctive approach to endurance performance enhancement that incorporates strategies designed to directly target RPE.

The chapters in this thesis bolster previous research illustrating that exhaustive endurance exercise is terminated at, or close to, maximum RPE. This, and specifically the findings in Chapters 2, 4, and 5, also supports growing body of evidence to suggest that RPE is a major determinant of physical endurance. Accordingly, these chapters reinforce the proposal made by the psychobiological model of performance that any physiological or psychological factor affecting RPE will alter endurance performance. Nevertheless, before this proposal can be fully accepted, more extensive research must be performed in endurance settings that comprise of longer distances and durations, and alternative modes of exercise.

These thesis chapters also support another tenet of the psychobiological model of endurance performance; specifically that exhaustion is determined by conscious and voluntary task termination, as opposed to physiological muscle fatigue or supraspinal fatigue. Again however, future psychobiological research must be combined with more sophisticated physiological manipulations and measures before this can be comprehensively validated. Where relevant, such research may also be assisted by measures of practical effect and the use of randomization tests for scenarios involving elite athletes and other special populations.

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APPENDICES

Appendix A: Motivational Self-talk Workbook

<u>Self Talk Cues</u>

Please read the following paragraph and work through the questions:

When you are exercising it is common to repeat certain phrases or words to yourself. These words and phrases are called self talk statements or cues. Some self talk statements have been found to improve sporting performance whereas other self talk statements have a negative effect on performance.

- ***<u>Think about the cycling task you have just completed</u>***
- Write down some of the self talk statements that you said to yourself which were phrased negatively (e.g. "I'm getting tired"). **Please do not feel that you must enter a self talk statement for <u>each</u> box, simply list as many as you can recall.**

1.
2.
3.
4.
5.
6.
7.
8.
9.
10.

It is important to realize that some negative self-talk statements are likely to be quite de-motivating (e.g., "The pain is too much") whereas others are likely to be quite motivating (e.g., "Don't give up" or "Get your arse in gear").

- In the following box please specify which of the negative self-talk statements listed on the previous page might be used as motivational statements for yourself.

- Please list your top 5 motivational statements below. However, if you do not view any of the negative self statements from the last page as motivational for yourself please leave the table blank.

1.
2.
3.
4.
5.

Please look at the above short list you have made and then look over and compare it to the following 12 statements listed below.

1. **Hang on in there**
2. **Drive forward**
3. **Come on up for it**
4. **Go for it**
5. **Dig Deep**
6. **Push it**
7. **You're a winner**
8. **Feeling good**
9. **You can do it**
10. **I can do this**
11. **You're doing well**
12. **Keep going, be strong**

From the **two lists** on the last page please pick **four statements** that you think would be **most beneficial** during the same cycling endurance task you have just completed.

When choosing these items please try and pick two statements that you think would be helpful when you are exercising normally and two statements that would be helpful when you are extremely fatigued and are close to the point of exhaustion.

Normal Exercise Stage
1.
2.
Exhaustion Stage
1.
2.

Now that you have chosen these four statements it is important that you learn to use self talk properly. To help you make the most of these statements there are two things to remember:

1. Over the next two weeks we would like you to make use of these statements during each training session that you are involved in (e.g. Cycling / Running). You should use the statements silently in your head – as often as you can remember to use them and whenever you think their use will be helpful.

2. When you are exercising at an intense level it is very likely that you will use unhelpful self talk statements that encourage you to 'give up' and withdraw effort. You have already filled out a list of negative statements that you said to yourself during the cycling task. However, it is possible to prevent yourself from 'giving up' by using a countering technique. Every time you hear yourself repeating a negative statement you should recognize it and respond with a positively worded statement. For example if you said to yourself "This hurts, I want to give up" you could respond with the phrase "Come on, you're better than that". This is a technique that endurance athletes have used successfully in the past.

Self Talk Workbook	
(Practice Session #1)	
Name:	Date:
Type of session:	Duration:

Instructions:
Having reviewed a list of possible self talk cues that might be helpful for you during a cycling endurance test, you picked 3 or 4 statements that you were asked to practice during a normal training session or game. Those items that you chose will be listed in the spaces provided on the last page. Please answer the following questions about your use of these statements during your most recent physical activity session.

a) Generally speaking to what extent did you remember to use the self talk statements during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all **Greatly**

b) Generally speaking, to what extent were you able to use the self talk statements during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all **Greatly**

In the following box please list one of your chosen self-statements:

1.

a. To what extent did you remember to use this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

b. Please specify the times when you used this statement (e.g., near the end of your workout when you were tiring? In the middle of the workout to maintain focus?)

Times:

c. To what extent did you use this statement to counter any negative statements you were saying to yourself?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

d. To what extent were you comfortable using this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all Comfortable **Very Comfortable**

e. Do you think this statement could have been **more** helpful during the session (e.g., could it be re-phrased more appropriately?)

YES or NO

f. If the statement could be more helpful please indicate how you could alter it to improve it. Please also write what the altered/edited self-talk statement actually is:

In the following box please list **ANOTHER** one of your chosen self-statements:

2.

a. To what extent did you remember to use this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

b. Please specify the times when you used this statement (e.g., near the end of your workout when you were tiring? In the middle of the workout to maintain focus?)

Times:

c. To what extent did you use this statement to counter any negative statements you were saying to yourself?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

d. To what extent were you comfortable using this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all Comfortable **Very Comfortable**

e. Do you think this statement could have been **more** helpful during the session (e.g., could it be re-phrased more appropriately?)

YES or NO

f. If the statement could be more helpful please indicate how you could alter it to improve it. Please also write what the altered/edited self-talk statement actually is:

In the following box please list **ANOTHER** one of your chosen self-statements:

3.

a. To what extent did you remember to use this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

b. Please specify the times when you used this statement (e.g., near the end of your workout when you were tiring? In the middle of the workout to maintain focus?)

Times:

c. To what extent did you use this statement to counter any negative statements you were saying to yourself?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

d. To what extent were you comfortable using this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all Comfortable **Very Comfortable**

e. Do you think this statement could have been **more** helpful during the session (e.g., could it be re-phrased more appropriately?)

YES or NO

f. If the statement could be more helpful please indicate how you could alter it to improve it. Please also write what the altered/edited self-talk statement actually is:

In the following box please list **ANOTHER** one of your chosen self-statements: **NB: If you only used 3 self talk statements please do no fill out this page!**

4.

a. To what extent did you remember to use this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

b. Please specify the times when you used this statement (e.g., near the end of your workout when you were tiring? In the middle of the workout to maintain focus?)

Times:

c. To what extent did you use this statement to counter any negative statements you were saying to yourself?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

d. To what extent were you comfortable using this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all Comfortable **Very Comfortable**

e. Do you think this statement could have been **more** helpful during the session (e.g., could it be re-phrased more appropriately?)

YES or **NO**

f. If the statement could be more helpful please indicate how you could alter it to improve it. Please also write what the altered/edited self-talk statement actually is:

In the spaces provided below list the self talk statements that you will use during your next workout. For example, if you have changed your statements to make them more helpful please list the new statements in the boxes below. On the other hand, if all of the statements are to remain in their original form please list them below in their unaltered form and remember to use them in your next session.

1.

2.

3.

4.

Please remember to use these exact statements (original or altered) in your next workout, as this will make them more effective.

Self Talk Workbook	
(Practice Session #2)	
Name:	Date:
Type of session:	Duration:

Instructions:
Having reviewed a list of possible self talk cues that might be helpful for you during a cycling endurance test, you picked 3 or 4 statements that you were asked to practice during a normal training session or game. Those items that you chose will be listed in the spaces provided on the last page. Please answer the following questions about your use of these statements during your most recent physical activity session.

c) Generally speaking to what extent did you remember to use the self talk statements during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all **Greatly**

d) Generally speaking, to what extent were you able to use the self talk statements during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all **Greatly**

In the following box please list one of your chosen self-statements:

1.

a. To what extent did you remember to use this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

b. Please specify the times when you used this statement (e.g., near the end of your workout when you were tiring? In the middle of the workout to maintain focus?)

Times:

c. To what extent did you use this statement to counter any negative statements you were saying to yourself?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

d. To what extent were you comfortable using this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all Comfortable **Very Comfortable**

e. Do you think this statement could have been **more** helpful during the session (e.g., could it be re-phrased more appropriately?)

YES or NO

f. If the statement could be more helpful please indicate how you could alter it to improve it. Please also write what the altered/edited self-talk statement actually is:

In the following box please list **ANOTHER** one of your chosen self-statements:

2.

a. To what extent did you remember to use this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

b. Please specify the times when you used this statement (e.g., near the end of your workout when you were tiring? In the middle of the workout to maintain focus?)

Times:

c. To what extent did you use this statement to counter any negative statements you were saying to yourself?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

d. To what extent were you comfortable using this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all Comfortable **Very Comfortable**

e. Do you think this statement could have been **more** helpful during the session (e.g., could it be re-phrased more appropriately?)

YES or NO

f. If the statement could be more helpful please indicate how you could alter it to improve it. Please also write what the altered/edited self-talk statement actually is:

In the following box please list **ANOTHER** one of your chosen self-statements:

3.

a. To what extent did you remember to use this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

b. Please specify the times when you used this statement (e.g., near the end of your workout when you were tiring? In the middle of the workout to maintain focus?)

Times:

c. To what extent did you use this statement to counter any negative statements you were saying to yourself?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

d. To what extent were you comfortable using this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all Comfortable **Very Comfortable**

e. Do you think this statement could have been **more** helpful during the session (e.g., could it be re-phrased more appropriately?)

YES or NO

f. If the statement could be more helpful please indicate how you could alter it to improve it. Please also write what the altered/edited self-talk statement actually is:

In the following box please list **ANOTHER** one of your chosen self-statements: **NB: If you only used 3 self talk statements please do no fill out this page!**

4.

a. To what extent did you remember to use this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

b. Please specify the times when you used this statement (e.g., near the end of your workout when you were tiring? In the middle of the workout to maintain focus?)

Times:

c. To what extent did you use this statement to counter any negative statements you were saying to yourself?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

d. To what extent were you comfortable using this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all Comfortable **Very Comfortable**

e. Do you think this statement could have been **more** helpful during the session (e.g., could it be re-phrased more appropriately?)

YES or NO

f. If the statement could be more helpful please indicate how you could alter it to improve it. Please also write what the altered/edited self-talk statement actually is:

In the spaces provided below list the self talk statements that you will use during your next workout. For example, if you have changed your statements to make them more helpful please list the new statements in the boxes below. On the other hand, if all of the statements are to remain in their original form please list them below in their unaltered form and remember to use them in your next session.

1.

2.

3.

4.

Please remember to use these exact statements (original or altered) in your next workout, as this will make them more effective.

Self Talk Workbook	
(Practice Session #3)	
Name:	Date:
Type of session:	Duration:

Instructions:
Having reviewed a list of possible self talk cues that might be helpful for you during a cycling endurance test, you picked 3 or 4 statements that you were asked to practice during a normal training session or game. Those items that you chose will be listed in the spaces provided on the last page. Please answer the following questions about your use of these statements during your most recent physical activity session.

e) Generally speaking to what extent did you remember to use the self talk statements during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all **Greatly**

f) Generally speaking, to what extent were you able to use the self talk statements during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all **Greatly**

In the following box please list one of your chosen self-statements:

1.

a. To what extent did you remember to use this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

b. Please specify the times when you used this statement (e.g., near the end of your workout when you were tiring? In the middle of the workout to maintain focus?)

Times:

c. To what extent did you use this statement to counter any negative statements you were saying to yourself?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

d. To what extent were you comfortable using this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all Comfortable **Very Comfortable**

e. Do you think this statement could have been **more** helpful during the session (e.g., could it be re-phrased more appropriately?)

YES or NO

f. If the statement could be more helpful please indicate how you could alter it to improve it. Please also write what the altered/edited self-talk statement actually is:

In the following box please list **ANOTHER** one of your chosen self-statements:

2.

a. To what extent did you remember to use this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

b. Please specify the times when you used this statement (e.g., near the end of your workout when you were tiring? In the middle of the workout to maintain focus?)

Times:

c. To what extent did you use this statement to counter any negative statements you were saying to yourself?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

d. To what extent were you comfortable using this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all Comfortable **Very Comfortable**

e. Do you think this statement could have been **more** helpful during the session (e.g., could it be re-phrased more appropriately?)

YES **or** **NO**

f. If the statement could be more helpful please indicate how you could alter it to improve it. Please also write what the altered/edited self-talk statement actually is:

In the following box please list **ANOTHER** one of your chosen self-statements:

3.

a. To what extent did you remember to use this statement during the session?

0	1	2	3	4	5	6	7	8	9	10

Never **All the time**

b. Please specify the times when you used this statement (e.g., near the end of your workout when you were tiring? In the middle of the workout to maintain focus?)

Times:

c. To what extent did you use this statement to counter any negative statements you were saying to yourself?

0	1	2	3	4	5	6	7	8	9	10

Never **All the time**

d. To what extent were you comfortable using this statement during the session?

0	1	2	3	4	5	6	7	8	9	10

Not at all Comfortable **Very Comfortable**

e. Do you think this statement could have been **more** helpful during the session (e.g., could it be re-phrased more appropriately?)

YES **or** **NO**

f. If the statement could be more helpful please indicate how you could alter it to improve it. Please also write what the altered/edited self-talk statement actually is:

In the following box please list **ANOTHER** one of your chosen self-statements: **NB: If you only used 3 self talk statements please do no fill out this page!**

4.

a. To what extent did you remember to use this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

b. Please specify the times when you used this statement (e.g., near the end of your workout when you were tiring? In the middle of the workout to maintain focus?)

Times:

c. To what extent did you use this statement to counter any negative statements you were saying to yourself?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

d. To what extent were you comfortable using this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all Comfortable **Very Comfortable**

e. Do you think this statement could have been **more** helpful during the session (e.g., could it be re-phrased more appropriately?)

YES or NO

f. If the statement could be more helpful please indicate how you could alter it to improve it. Please also write what the altered/edited self-talk statement actually is:

In the spaces provided below list the self talk statements that you will use during your next workout. For example, if you have changed your statements to make them more helpful please list the new statements in the boxes below. On the other hand, if all of the statements are to remain in their original form please list them below in their unaltered form and remember to use them in your next session.

1.

2.

3.

4.

Please remember to use these exact statements (original or altered) in your next workout, as this will make them more effective.

Self Talk Workbook	
(Practice Session #4)	
Name:	Date:
Type of session:	Duration:

Instructions:
Having reviewed a list of possible self talk cues that might be helpful for you during a cycling endurance test, you picked 3 or 4 statements that you were asked to practice during a normal training session or game. Those items that you chose will be listed in the spaces provided on the last page. Please answer the following questions about your use of these statements during your most recent physical activity session.

a) Generally speaking to what extent did you remember to use the self talk statements during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all **Greatly**

b) Generally speaking, to what extent were you able to use the self talk statements during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all **Greatly**

In the following box please list one of your chosen self-statements:

1.

a. To what extent did you remember to use this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

b. Please specify the times when you used this statement (e.g., near the end of your workout when you were tiring? In the middle of the workout to maintain focus?)

Times:

c. To what extent did you use this statement to counter any negative statements you were saying to yourself?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

d. To what extent were you comfortable using this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all Comfortable **Very Comfortable**

e. Do you think this statement could have been **more** helpful during the session (e.g., could it be re-phrased more appropriately?)

YES or NO

f. If the statement could be more helpful please indicate how you could alter it to improve it. Please also write what the altered/edited self-talk statement actually is:

In the following box please list **ANOTHER** one of your chosen self-statements:

2.

a. To what extent did you remember to use this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

b. Please specify the times when you used this statement (e.g., near the end of your workout when you were tiring? In the middle of the workout to maintain focus?)

Times:

c. To what extent did you use this statement to counter any negative statements you were saying to yourself?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

d. To what extent were you comfortable using this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all Comfortable **Very Comfortable**

e. Do you think this statement could have been **more** helpful during the session (e.g., could it be re-phrased more appropriately?)

YES or NO

f. If the statement could be more helpful please indicate how you could alter it to improve it. Please also write what the altered/edited self-talk statement actually is:

In the following box please list **ANOTHER** one of your chosen self-statements:

3.

a. To what extent did you remember to use this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

b. Please specify the times when you used this statement (e.g., near the end of your workout when you were tiring? In the middle of the workout to maintain focus?)

Times:

c. To what extent did you use this statement to counter any negative statements you were saying to yourself?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

d. To what extent were you comfortable using this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all Comfortable **Very Comfortable**

e. Do you think this statement could have been **more** helpful during the session (e.g., could it be re-phrased more appropriately?)

YES or NO

f. If the statement could be more helpful please indicate how you could alter it to improve it. Please also write what the altered/edited self-talk statement actually is:

In the following box please list **ANOTHER** one of your chosen self-statements: **NB: If you only used 3 self talk statements please do no fill out this page!**

4.

a. To what extent did you remember to use this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

b. Please specify the times when you used this statement (e.g., near the end of your workout when you were tiring? In the middle of the workout to maintain focus?)

Times:

c. To what extent did you use this statement to counter any negative statements you were saying to yourself?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

d. To what extent were you comfortable using this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all Comfortable **Very Comfortable**

e. Do you think this statement could have been **more** helpful during the session (e.g., could it be re-phrased more appropriately?)

YES or NO

f. If the statement could be more helpful please indicate how you could alter it to improve it. Please also write what the altered/edited self-talk statement actually is:

In the spaces provided below list the self talk statements that you will use during your next workout. For example, if you have changed your statements to make them more helpful please list the new statements in the boxes below. On the other hand, if all of the statements are to remain in their original form please list them below in their unaltered form and remember to use them in your next session.

1.

2.

3.

4.

Please remember to use these exact statements (original or altered) in your next workout, as this will make them more effective.

Self Talk Workbook	
(Practice Session #5)	
Name:	Date:
Type of session:	Duration:

Instructions:
Having reviewed a list of possible self talk cues that might be helpful for you during a cycling endurance test, you picked 3 or 4 statements that you were asked to practice during a normal training session or game. Those items that you chose will be listed in the spaces provided on the last page. Please answer the following questions about your use of these statements during your most recent physical activity session.

a) Generally speaking to what extent did you remember to use the self talk statements during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all **Greatly**

b) Generally speaking, to what extent were you able to use the self talk statements during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all **Greatly**

In the following box please list one of your chosen self-statements:

1.

a. To what extent did you remember to use this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

b. Please specify the times when you used this statement (e.g., near the end of your workout when you were tiring? In the middle of the workout to maintain focus?)

Times:

c. To what extent did you use this statement to counter any negative statements you were saying to yourself?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

d. To what extent were you comfortable using this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all Comfortable **Very Comfortable**

e. Do you think this statement could have been **more** helpful during the session (e.g., could it be re-phrased more appropriately?)

YES or NO

f. If the statement could be more helpful please indicate how you could alter it to improve it. Please also write what the altered/edited self-talk statement actually is:

In the following box please list **ANOTHER** one of your chosen self-statements:

2.

a. To what extent did you remember to use this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

b. Please specify the times when you used this statement (e.g., near the end of your workout when you were tiring? In the middle of the workout to maintain focus?)

Times:

c. To what extent did you use this statement to counter any negative statements you were saying to yourself?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

d. To what extent were you comfortable using this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all Comfortable **Very Comfortable**

e. Do you think this statement could have been **more** helpful during the session (e.g., could it be re-phrased more appropriately?)

YES or NO

f. If the statement could be more helpful please indicate how you could alter it to improve it. Please also write what the altered/edited self-talk statement actually is:

In the following box please list **ANOTHER** one of your chosen self-statements:

3.

a. To what extent did you remember to use this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

b. Please specify the times when you used this statement (e.g., near the end of your workout when you were tiring? In the middle of the workout to maintain focus?)

Times:

c. To what extent did you use this statement to counter any negative statements you were saying to yourself?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

d. To what extent were you comfortable using this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all Comfortable **Very Comfortable**

e. Do you think this statement could have been **more** helpful during the session (e.g., could it be re-phrased more appropriately?)

YES or NO

f. If the statement could be more helpful please indicate how you could alter it to improve it. Please also write what the altered/edited self-talk statement actually is:

In the following box please list **ANOTHER** one of your chosen self-statements: **NB: If you only used 3 self talk statements please do no fill out this page!**

4.

a. To what extent did you remember to use this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

b. Please specify the times when you used this statement (e.g., near the end of your workout when you were tiring? In the middle of the workout to maintain focus?)

Times:

c. To what extent did you use this statement to counter any negative statements you were saying to yourself?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

d. To what extent were you comfortable using this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all Comfortable **Very Comfortable**

e. Do you think this statement could have been **more** helpful during the session (e.g., could it be re-phrased more appropriately?)

YES **or** **NO**

f. If the statement could be more helpful please indicate how you could alter it to improve it. Please also write what the altered/edited self-talk statement actually is:

In the spaces provided below list the self talk statements that you will use during your next workout. For example, if you have changed your statements to make them more helpful please list the new statements in the boxes below. On the other hand, if all of the statements are to remain in their original form please list them below in their unaltered form and remember to use them in your next session.

1.

2.

3.

4.

Please remember to use these exact statements (original or altered) in your next workout, as this will make them more effective.

Self Talk Workbook	
(Practice Session #6)	
Name:	Date:
Type of session:	Duration:

Instructions:
Having reviewed a list of possible self talk cues that might be helpful for you during a cycling endurance test, you picked 3 or 4 statements that you were asked to practice during a normal training session or game. Those items that you chose will be listed in the spaces provided on the last page. Please answer the following questions about your use of these statements during your most recent physical activity session.

a) Generally speaking to what extent did you remember to use the self talk statements during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all **Greatly**

b) Generally speaking, to what extent were you able to use the self talk statements during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all **Greatly**

In the following box please list one of your chosen self-statements:

1.

a. To what extent did you remember to use this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

b. Please specify the times when you used this statement (e.g., near the end of your workout when you were tiring? In the middle of the workout to maintain focus?)

Times:

c. To what extent did you use this statement to counter any negative statements you were saying to yourself?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

d. To what extent were you comfortable using this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all Comfortable **Very Comfortable**

e. Do you think this statement could have been **more** helpful during the session (e.g., could it be re-phrased more appropriately?)

YES or NO

f. If the statement could be more helpful please indicate how you could alter it to improve it. Please also write what the altered/edited self-talk statement actually is:

In the following box please list **ANOTHER** one of your chosen self-statements:

2.

a. To what extent did you remember to use this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

b. Please specify the times when you used this statement (e.g., near the end of your workout when you were tiring? In the middle of the workout to maintain focus?)

Times:

c. To what extent did you use this statement to counter any negative statements you were saying to yourself?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

d. To what extent were you comfortable using this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all Comfortable **Very Comfortable**

e. Do you think this statement could have been **more** helpful during the session (e.g., could it be re-phrased more appropriately?)

YES or NO

f. If the statement could be more helpful please indicate how you could alter it to improve it. Please also write what the altered/edited self-talk statement actually is:

In the following box please list **ANOTHER** one of your chosen self-statements:

3.

a. To what extent did you remember to use this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

b. Please specify the times when you used this statement (e.g., near the end of your workout when you were tiring? In the middle of the workout to maintain focus?)

Times:

c. To what extent did you use this statement to counter any negative statements you were saying to yourself?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

d. To what extent were you comfortable using this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all Comfortable **Very Comfortable**

e. Do you think this statement could have been **more** helpful during the session (e.g., could it be re-phrased more appropriately?)

YES or NO

f. If the statement could be more helpful please indicate how you could alter it to improve it. Please also write what the altered/edited self-talk statement actually is:

In the following box please list **ANOTHER** one of your chosen self-statements: **NB: If you only used 3 self talk statements please do no fill out this page!**

4.

a. To what extent did you remember to use this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

b. Please specify the times when you used this statement (e.g., near the end of your workout when you were tiring? In the middle of the workout to maintain focus?)

Times:

c. To what extent did you use this statement to counter any negative statements you were saying to yourself?

0 1 2 3 4 5 6 7 8 9 10

Never **All the time**

d. To what extent were you comfortable using this statement during the session?

0 1 2 3 4 5 6 7 8 9 10

Not at all Comfortable **Very Comfortable**

e. Do you think this statement could have been **more** helpful during the session (e.g., could it be re-phrased more appropriately?)

YES or NO

f. If the statement could be more helpful please indicate how you could alter it to improve it. Please also write what the altered/edited self-talk statement actually is:

In the spaces provided below list the self talk statements that you will use during your next workout. For example, if you have changed your statements to make them more helpful please list the new statements in the boxes below. On the other hand, if all of the statements are to remain in their original form please list them below in their unaltered form and remember to use them in your next session.

1.

2.

3.

4.

Please remember to use these exact statements (original or altered) in your next workout, as this will make them more effective.

Appendix B: Motivational Self-talk Manipulation Checks

Control Group - Post Test Questionnaire

Name: ____ Date: ____________

1. To what extent where you able to adhere to the instructions you were give before and during the cycling task?

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

2. Did you use any form of self-talk statements during the task?

Yes / No

3. If yes, please list any statements that you made in the spaces below and indicate how many times you used this statement. Please add one phrase per box and do not feel pressurised to complete every blank box. More spaces have deliberately been included that necessary.

1)

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

2)

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

3)

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

4)

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

5)

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

6)

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

7)

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

8)

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

4. Did you use any additional psychological strategies during the cycling task?
For example, goal setting, imagery, relaxation

Yes/ No

If yes, please state in the box below, any specific strategies that you used

Self-talk Group - Post Test Questionnaire

Name: ______________________________________ Date: ___________

1. To what extent where you able to adhere to the instructions that you were given before and during the cycling task?

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

2. Did you use any form of self-talk statements during the task?

Yes / No

3. Please circle either yes or no for each of the following statements to indicate whether you used the statement during the previous cycling task. Should you a circle yes to any of the below statements please specify on the scale provided the extent to which you used the statement

Insert Statement: **Yes / No**

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

Insert Statement **Yes / No**

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

Insert Statement **Yes / No**

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

Insert Statement **Yes / No**

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

Insert Statement **Yes / No**

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

Insert Statement **Yes / No**

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

Insert Statement **Yes / No**

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

Insert Statement **Yes / No**

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

Insert Statement **Yes / No**

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

Insert Statement **Yes / No**

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

Insert Statement **Yes / No**

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

Insert Statement **Yes / No**

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

3. Please use the following spaces to report anything else that you said to yourself and how often you said it. Please write on phrase per box. Don't feel pressurised to complete all of the boxes. We have deliberately provided more spaces than may be necessary.

1)

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

2)

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

3)

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

4)

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

5)

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

6)

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

7)

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

8)

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

9)

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

10)

0	1	2	3	4	5	6	7	8	9	10

Not at all *Greatly*

4. Did you use any additional strategies e.g. Imagery, goal setting, breathing techniques or relaxation when performing the cycling task.

Yes / No

If yes, please state in the space below the additional strategies that you used during the cycling task.

5. Overall, how useful were the self-talk statements during the exercise

0	1	2	3	4	5	6	7	8	9	10

Not at all Useful *Very Useful*

Appendix C: Modified Borg CR10 Scale and Instructions

Rating of Perceived Exertion

0	No effort at all
0.5	Very, very light
1	Very light
2	Light
3	Moderate
4	Somewhat hard
5	Hard (heavy)
6	
7	Very hard
8	
9	Very, very hard
10	"Maximal" effort
*	

INSTRUCTIONS FOR RATING OF PERCEIVED EXERTION (RPE) SCALE

We ask you to rate your perceived exertion, that is, how effortful, strenuous and fatiguing the exercise feels to you. This depends mainly on how hard you have to drive your legs and/or arms, and how heavy is your breathing. You must only attend to your subjective feelings of effort and not to the physiological cues or what the actual physical load is.

10, *"Maximal" effort*, is the main anchor. It is the highest effort you have ever experienced. It may be possible, however, to experience an even higher effort. Therefore, the symbol * is placed somewhat further down the scale without a fixed number. If you perceive an effort higher than 10, you may use a higher number that better reflects your feelings, for example 11 or 12.

When rating your perceived exertion, start with a *verbal expression* and then choose a number. If your perception of effort is *Very light*, rate 1; if it is *Moderate*, rate 3; and so on. You are welcome to use half values such as 1.5 or 3.5. It is very important that you answer what <u>you</u> perceive and not what you believe you ought to answer. Be as honest as possible and try not to overestimate or underestimate the intensity of your effort. It is important to remember that there are no right or wrong answers.

Examples

1	Is very light, like walking slowly at your own pace or lifting a small weight.
3	Is not especially hard; it feels fine, and it is no problem to continue.
5	You are tired, but you don't have any great difficulties.
7	You can still go on but have to push yourself very much; you are very tired.
10	This is as hard as most people have ever experienced in their lives.
*	This is a feeling of effort stronger than the strongest feeling you have ever perceived before; therefore, you can give a number higher than 10.

Appendix D: Brunel Mood Scale (BRUMS)

Name: ______________________________ *Date:* ____________________

Visit: ______________________________ *Time:* ____________________

Below is a list of words that describe feelings. Read each one carefully and then circle the corresponding number that best describes HOW YOU FEEL RIGHT NOW. Please ensure that you answer every question.

0 = not at all 1 = a little 2 = moderately 3 = quite a bit 4 = extremely

1. Panicky..........	0	1	2	3	4
2. Lively..........	0	1	2	3	4
3. Confused..........	0	1	2	3	4
4. Worn Out..........	0	1	2	3	4
5. Depressed..........	0	1	2	3	4
6. Downhearted..........	0	1	2	3	4
7. Annoyed..........	0	1	2	3	4
8. Exhausted..........	0	1	2	3	4
9. Mixed-up..........	0	1	2	3	4
10. Sleepy..........	0	1	2	3	4
11. Bitter..........	0	1	2	3	4
12. Unhappy..........	0	1	2	3	4
13. Anxious..........	0	1	2	3	4
14. Worried..........	0	1	2	3	4
15. Energetic..........	0	1	2	3	4
16. Miserable..........	0	1	2	3	4
17. Muddled..........	0	1	2	3	4
18. Nervous..........	0	1	2	3	4
19. Angry..........	0	1	2	3	4
20. Active..........	0	1	2	3	4
21. Tired..........	0	1	2	3	4
22. Bad tempered..........	0	1	2	3	4
23. Alert..........	0	1	2	3	4
24. Uncertain..........	0	1	2	3	4

Appendix E: Success and Intrinsic Motivation Scale

Name: ______________________ *Date:* ______________

Visit: ______________________ *Time:* ______________

Please answer the following questions about your attitude towards the task that you are about to do (Endurance test to exhaustion on a cycle ergometer). Rate your agreement with the statements below by circling only one of the answers. Please be certain to answer every question.

0 = not at all   1 = a little bit   2 = somewhat   3 = very much   4 = extremely

1. I expect the content of the task will be interesting	0	1	2	3	4
2. The only reason to do the task is to get an external reward	0	1	2	3	4
3. I would rather spend the time doing the task on something else	0	1	2	3	4
4. I am concerned about not doing as well as I can	0	1	2	3	4
5. I want to perform better than most people do	0	1	2	3	4
6. I will become fed up with the task	0	1	2	3	4
7. I am eager to do well	0	1	2	3	4
8. I would be disappointed if I failed to do well on the task	0	1	2	3	4
9. I am committed to attaining my performance goals	0	1	2	3	4
10. Doing the task is worthwhile	0	1	2	3	4
11. I expect to find the task boring	0	1	2	3	4
12. I feel apathetic about my performance	0	1	2	3	4
13. I want to succeed on the task	0	1	2	3	4
14. The task will bring out my competitive drive	0	1	2	3	4
15. I am motivated to do the task	0	1	2	3	4

Appendix F: Subliminal Affective Priming – Funnelled Debrief

Name: ______________________________ *Date:* ____________________

Visit: ______________________________ *Time:* ____________________

Please answer each of the questions blow as honestly as possible:

1. What do you think the purposes of this experiment (the whole thing) was or was trying to study?

2. Did anything about the experiment seem strange to you, or was there anything that you were wondering about?

3. Did you think that the two tasks (cycling and computer task) were related in any way? If yes, in what way were they related?

4. Did anything on the computer screen affect what you did during the cycling task? If yes, how exactly did it affect you?

5. What did you think that the patterned flashes were on the computer screen? Be as specific as possible?

6. If anything, what did you notice in or before the flashes?

Appendix G: UWIST Mood Adjective Checklist

Name: ______________________ *Date:* ______________

Visit: ______________________ *Time:* ______________

Below is a list of words that describe feelings. Read each one carefully and then circle the corresponding number that best describes HOW YOU FEEL RIGHT NOW. Please ensure that you answer every question.

1 = not at all 2 3 4 = moderately 5 6 7 = very much

Right now I'm feeling

1. Happy..........	1	2	3	4	5	6	7
2. Joyful	1	2	3	4	5	6	7
3. Frustrated..........	1	2	3	4	5	6	7
4. Sad..........	1	2	3	4	5	6	7
5. Contented..........	1	2	3	4	5	6	7
6. Depressed..........	1	2	3	4	5	6	7
7. Cheerful..........	1	2	3	4	5	6	7
8. Dissatisfied..........	1	2	3	4	5	6	7

Appendix H: Subliminal Action and Inaction Words Priming – Funnelled Debrief

Name: ______________________ *Date:* ______________

Visit: ______________________ *Time:* ______________

Please answer each of the questions blow as honestly as possible:

1. What do you think the purposes of this experiment (the whole thing) was, or was trying to study?

2. Did anything about the experiment seem strange to you, or was there anything that you were wondering about?

3. Did you think that the two tasks (cycling and computer task) were related in any way? If yes, in what way were they related?

4. Did anything on the computer screen affect what you did during the cycling task? If yes, how exactly did it affect you?

5. What did you think that the letters represented on the computer screen? Be as specific as possible.

6. *If anything*, what did you notice in the letters or before them?